ANALYSIS OF ALBERTA TEMPERATURE OBSERVATIONS AND ESTIMATES BY GLOBAL CLIMATE MODELS

Alberta
ENVIRONMENT

ANALYSIS OF ALBERTA TEMPERATURE OBSERVATIONS AND ESTIMATES BY GLOBAL CLIMATE MODELS

Prepared by:

C.L.A. Chaikowsky
Student Intern
Environmental Physical Sciences
University of Alberta

for

Science and Technology Branch
Environmental Sciences Division
Alberta Environment

October 2000

Pub. No: T/562
ISBN: 0-7785-1392-0 (Printed Edition)
ISBN: 0-7785-1394-7 (On-Line Edition)
Web Site: http://www.gov.ab.ca/env/

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Environmental Sciences Division
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-5883
Fax: (780) 422-4192

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

FOREWORD

The assessment of the regional impacts of climate change and the development of adaptation strategies require climate information at the regional level. It is known that present-day climate models cannot provide reliable estimates of climate parameters at such spatial scales. For the province of Alberta, the diversity of landscapes means significant diversity in climate. There are also significant differences in the way local climate changes in space and time. Such differences are important factors to be considered in policy development.

The purpose of this study was to examine the spatial and temporal variability of temperature over the province of Alberta based on observed records, and to compare the results with climate model outputs. The emphasis is on temperature trends to allow for a detailed analysis of both annual and monthly data. The results from this study are useful to the understanding of the nature and extent of temperature variability within the province. They are also useful in developing strategies for climate change adaptation for Alberta.

This report is one of three prepared by Ms. C. Chaikowsky during her internship with Alberta Environment from the Environmental Physical Sciences Program at the University of Alberta.

Raymond Wong, Ph.D.
Student Intern Co-Supervisor
Science and Technology Branch
Environmental Sciences Division

SUMMARY

Mean, minimum, and maximum temperature trends were investigated for the province of Alberta. Measured temperature data from 25 Alberta climate stations were used to identify annual and monthly temperature trends observed in the province, and outputs from a GCM (global climate model) were used to estimate annual trends. Trends in the minimum and maximum temperatures were compared, and these trends were compared to the trends estimated using GCM outputs. In addition to analyzing the observed temperature trends spatially, a temporal analysis was performed to investigate the effect of time period on the magnitude of temperature trends in Alberta.

Observed temperature trends were examined over two time periods, 1938–1995 and 1960–1995. The observational temperature data indicate that Alberta has undergone warming since the 1930s. The mean temperature increase over the 1938–1995 period was 0.6°C, or 0.1°C/decade. Over the more recent time period, 1960–1995, mean temperature increased 1.3°C, or at an average rate of 0.4°C/decade. Therefore, the rate of mean temperature increase over the shorter, more recent time period was four times the rate of increase over the longer time period. In addition, more stations had statistically significant trends over the more recent time period.

Minimum temperatures in Alberta increased more than maximums over the 1938–1995 period. Conversely, over the 1960–1995 period, minimum and maximum temperatures increased at comparable rates, with the maximum increasing only 0.02°C more per decade than the minimum. Over both periods, more stations had significant minimum temperature trends than significant maximum temperature trends.

The greatest warming trend in Alberta over the 1938–1995 period was found in west-central Alberta, at Banff, where the mean temperature increased 0.22°C/decade on average. The greatest cooling trend was found in the southwestern corner of Alberta, at Carway, where the mean temperature underwent a decrease of 0.01°C/decade. Warming was greater over the 1960–1995 period and no cooling took place. The greatest warming trend in Alberta over the 1960–1995 period was 0.56°C/decade, at Beaverlodge.

Cooling over the period of 1938–1995 occurred in July–December, with the greatest cooling in November at most stations. Warming occurred in the months of January–July, with the greatest warming in March. The greatest warming occurred in the month of March at almost all of the Alberta stations, regardless of the overall annual trend. At a few Alberta stations, cooling trends were more substantial in some months and cancelled out the warming trends in other months to some extent. Little mean warming was observed at such stations. Even at stations with net annual cooling, however, March was still the month with the greatest warming trend. The greatest magnitude of monthly warming was found in the maximum temperature, and mainly for the southern stations.

GCM outputs estimated a mean warming trend of approximately 0.3°C/decade for Alberta over the 1900–2100 period, with greater increases in the minimum temperature than in the maximum. The amounts of warming estimated over the 1938–1995 and 1960–1995 periods were less than the warming actually observed in Alberta over these periods. The most substantial warming was estimated following the year 2000. Over the 2000–2100 period, the GCM run that included only greenhouse gas forcing estimated a mean increase of 5°C.

The GCM results differed greatly from observations at the scale of Alberta. The warming actually observed in Alberta was 0.5°C – 1.0°C greater than the GCM simulations. Overall, the GCM outputs were not useful in estimating temperature variation at the scale of Alberta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Greatest thanks are extended to Raymond Wong of Alberta Environment for facilitating this study, as well as assisting with the statistical analysis.

This project could not have been completed without measured temperature data, which were supplied by Environment Canada at Downsview, Ontario, as well as GCM data, supplied by the Canadian Centre for Climate Modelling and Analysis.

I would also like to thank Jamie Ayers of Alberta Environment for supplying an Alberta base map in suitable coordinates for use in plotting the temperature trends.

ABBREVIATIONS

A	Airport
AR	Autoregressive
CCCMA	Canadian Centre for Climate Modelling and Analysis
CDA	Canadian Department of Agriculture
CGCMI	Canadian Global Coupled Model (version I)
CHTD	Canadian Historical Temperature Database
CO_2	Carbon dioxide
EC	Environment Canada
ENSO	El Niño southern oscillation
FPE	Final prediction error
GCM	Global climate model or general circulation model
GHG	Greenhouse gas
GHG+A	Greenhouse gas plus aerosol
IPCC	Intergovernmental Panel on Climate Change

1.0 INTRODUCTION

The subject of global climate change frequents the media headlines, yet the phenomenon is hardly new when viewed from a historical perspective. The earth has undergone climate variation—from ice ages to warm interglacial periods—since the beginning of time. The way climate change is viewed, however, depends upon the time frame of reference.

Many atmospheric scientists express concern about whether humans are contributing to climatic variation and causing climate change to occur at an increased rate. The increase in anthropogenic emissions of carbon dioxide (CO_2) continues to be studied as a likely contributor to global warming. According to some estimates, potential global warming, enhanced by the effect of increased CO_2 and other greenhouse gases (the enhanced greenhouse effect), could be greater in magnitude and occur faster than any other climate change in the 10 000-year history of civilization (Moran and Morgan, 1997). However, the global climate is naturally variable and there are uncertainties as to whether the warming within the last century reflects natural climate oscillations or human activity.

Climate change is not only a topic of research at the global scale, but is also a regional issue. The widely variable terrain of Alberta, ranging from flat prairies to mountain wilderness, features a corresponding variety of different climate regimes. One area of concern that has been raised is how a warmer climate would affect Alberta's resource-based industries, agriculture, for example. Environment Canada identifies the following as potential impacts of climate change on the prairies: (i) increased water demand and drying up of wetlands, (ii) reduced crop yield due to increased temperature and lower soil moisture, or conversely (iii) a lengthened growing season and increased crop production as a result of higher temperatures (EC, 1999c). These findings illustrate the current uncertainty as to whether warming in Alberta would have negative and/or positive effects on vegetation and hydrology.

Wheaton (1998) states that ecosystems in the prairie provinces are particularly sensitive to small changes in average temperature. The average annual temperature of the parklands is about 2°C higher than that of the forest region, suggesting the size of temperature increase that might result in a transformation from forest to parkland.

Recent studies have shown that the Canadian prairies have become warmer in the last four to five decades and that the warming has occurred especially in the months of January, March, April, and June (Gan, 1998). Generally, this warming has been attributed to a rise in the minimum temperature. On a global scale, Karl et al. (1993) found that the rise in minimum temperature has occurred at a rate three times that of the maximum temperature from 1951 to 1990. Similarly, Shen (1999) reports that the maximum temperature in Alberta does not exhibit an upward trend, but the minimum temperature has clearly been increasing since approximately 1920.

The purpose of this study was to identify patterns and trends in temperature variation in Alberta and to evaluate the capabilities of climate models to predict temperature change. The following questions are addressed: Are temperatures in Alberta rising? Are there significant trends in the minimum/maximum temperature? How do temperature trends vary spatially across Alberta? Is there one region in Alberta where warming is most significant? Can climate models predict the actual temperature variation that occurs in Alberta?

The study area consists of the province of Alberta and includes 25 climate observation stations scattered across the province (Figure 1.1). These stations are listed in Table 1.1, which gives the full station names, location coordinates, and available data lengths. The abbreviations ‘A’ and ‘CDA’ following some station names refer to airport and Canadian Department of Agriculture (Agriculture Canada) stations, respectively.

This report comprises analyses of historical temperature data from Alberta climate stations (Table 1.1) and output from global climate models (GCMs). Alberta temperature data were supplied by Environment Canada at Downsview, Ontario, and were part of a rehabilitated temperature data set called the Canadian Historical Temperature Database. The data have been adjusted for inconsistencies arising from factors such as equipment changes, observer changes, and relocation of stations (Vincent and Gullet, 1999; Vincent, 1997). Further description of these data is given in section 3.1. The historical climate data from the 25 Alberta stations were used to provide spatial pictures of annual mean, minimum, and maximum temperature trends in Alberta over the past number of decades. A seasonal trend analysis was also performed using the historical temperature data, in order to identify the month(s) when the most warming/cooling occurred.

GCM outputs were obtained on-line from the Canadian Centre for Climate Modelling and Analysis (described in section 3.3). Trends in the mean, minimum, and maximum temperatures were estimated using the GCM output and these estimates were compared to the data trends actually observed in Alberta.

In addition, temporal analyses were performed on both the observational and the GCM data. Variations in the magnitudes of warming trends in Alberta for different time periods were investigated. Estimated and observed trends were also compared over different temporal scales; for example, one decade was compared to the previous decade in order to identify periods of significant warming.

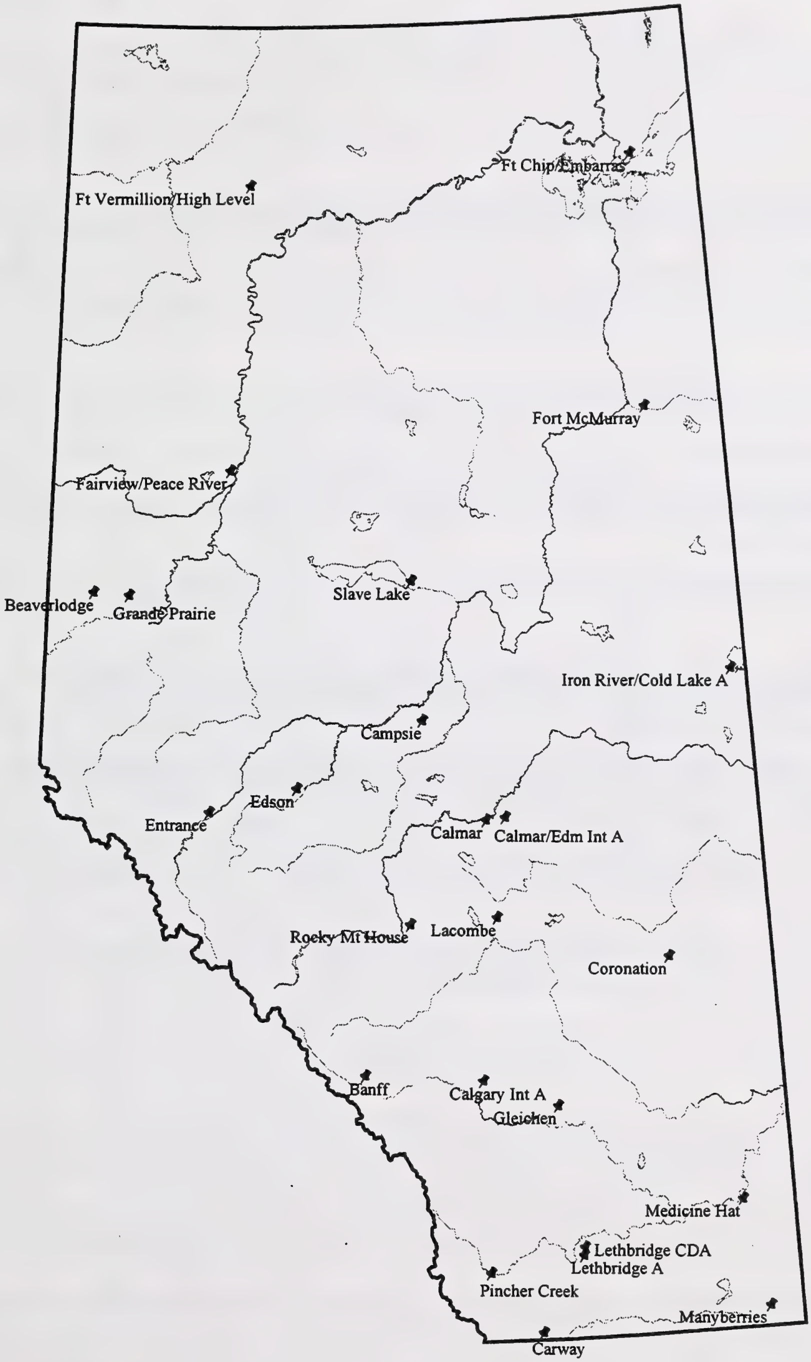


Figure 1.1 Study area

Table 1.1 Alberta climate station locations and periods of record

Station Name	Longitude		Latitude		Period
	Deg	*Min*	*Deg*	*Min*	
Banff	115	34	51	11	1895-1995
Beaverlodge CDA	119	24	55	12	1913-1995
Calgary Int A	114	01	51	07	1895-1995
Calmar	113	51	53	17	1915-1995
Campsie	114	41	54	08	1912-1995
Carway	113	22	49	00	1914-1995
Iron River / Cold Lake A	110	17	54	25	1925-1995
Coronation / Coronation A	111	27	52	04	1924-1995
Calmar / Edmonton Int A	113	35	53	18	1916-1995
Edson / Edson / Edson A	116	28	53	35	1914-1995
Entrance	117	41	53	23	1917-1995
Fort Chipewyan / Embarras A / Fort Chipewyan A	111	07	58	46	1895-1995
Fort McMurray / Fort McMurray A	111	13	56	39	1908-1995
Gleichen	113	03	50	53	1903-1995
Grande Prairie / Grande Prairie A	118	53	55	11	1922-1995
Fort Vermilion CDA / High Level A	117	10	58	37	1908-1995
Lacombe CDA	113	45	52	28	1907-1995
Lethbridge A	112	48	49	38	1938-1995
Lethbridge / Lethbridge CDA	112	47	49	42	1902-1995
Manyberries CDA	110	28	49	07	1928-1995
Medicine Hat A	110	43	50	01	1895-1995
Fairview / Peace River A	117	26	56	14	1931-1995
Pincher Creek Town / Pincher Creek / Pincher Creek A	114	00	49	31	1895-1995
Rocky M H / Rocky M H / Rocky Mt House (Aut)	114	55	52	26	1915-1995
Slave Lake / Slave Lake A	114	47	55	18	1922-1995

2.0 BACKGROUND

Climate is the average weather conditions and their variability over a particular area and time period. Climate variation is typically observed over a period of 30 years, whereas weather involves short-term (day-to-day) variations in climatic parameters, such as surface temperature (Finlayson-Pitts and Pitts, 2000).

Global warming has commonly been linked with increased anthropogenic CO_2 emissions and the enhanced greenhouse effect (Trefil, 1999). The enhanced greenhouse effect is not the sole means by which warming occurs, however. Climatic variation is a complex response to the interactions of many processes within and outside the earth-atmosphere system, including (Moran and Morgan, 1997):

(i) fluctuations in the solar constant (flux of solar radiation to the earth's atmosphere),
(ii) changes in the earth's orbit and axis of rotation
(iii) the planetary albedo (percent of solar radiation reflected by the earth and/or atmosphere),
(iv) changes in the gas and aerosol composition of the atmosphere; and
(v) large-scale atmospheric oscillations (such as the southern oscillation and associated El Niño)

2.1 Factors Affecting Temperature

Changes in the solar energy received at the earth's surface occur naturally as a result of periodic variation in the earth's orbit and the tilt of the earth's axis (EC, 1997). Changes to the planetary albedo may be caused by several different mechanisms. Increased cloud cover (as a result of pollution-induced aerosols, for example) increases the albedo, causing more solar radiation to be reflected and producing a cooling effect (Finlayson-Pitts and Pitts, 2000). However, clouds can also have a warming effect on the troposphere, as clouds absorb and emit longwave terrestrial radiation (Moran and Morgan, 1997).

Aerosols have the direct effect of scattering and reflecting incoming solar radiation, thereby increasing the albedo and causing cooling. Some aerosols can also cause cooling indirectly by acting as cloud nuclei and increasing the cloud albedo (Khandekar, 2000). On the other hand, some aerosols can absorb and emit terrestrial radiation to induce warming (Finlayson-Pitts and Pitts, 2000).

Deforestation decreases the earth's albedo and induces warming, since vegetation reflects more solar radiation than bare soil does. Forests are also sinks of carbon dioxide, and deforestation contributes to an increase of CO_2 in the atmosphere. Urbanization (the transformation of soil, vegetation, etc. to concrete and other man-made materials) can also affect the surface energy balance and lead to localized warming.

The highest local mean temperatures tend to occur in large urban centres (Calgary and Edmonton, for example) as a result the urban heat island effect (Wong et al., 1989). The term urban heat island describes the tendency for air temperatures in cities to be higher than those of the surrounding rural area. This climatic effect intensifies with urbanization, so that the size of the urban area influences both the magnitude and aerial extent of climatic impact (Moran and Morgan, 1997). Moran and Morgan (1997) outline three factors that contribute to the development of an urban heat island:

(i) a high concentration of heat sources in cities (people, cars, industry, furnaces, etc.)
(ii) loss of heat into city air at night by conductive building materials (concrete, asphalt, brick, etc.)
(iii) lower evapotranspiration rates, typical in cities—less absorbed radiation is used for evaporation and more is used for directly heating the ground and air

Changes in the gas and aerosol composition of the atmosphere are sometimes attributed to human activity. As mentioned, aerosols can have a cooling effect by reflecting and scattering solar radiation (Finlayson-Pitts and Pitts, 2000). Emissions of SO_2 from fossil fuel burning, as well as other emissions from biomass burning, have increased aerosol concentrations (Wigley, 1999). Wigley (1999) notes that this increase in atmospheric aerosols is important because the cooling effect of sulphate aerosols could partially offset the warming effect of greenhouse gases.

Gases that absorb infrared heat energy that is radiated from earth (water vapour, carbon dioxide, and methane are some examples) contribute to what has been termed the greenhouse effect and are referred to as greenhouses gases (EC, 1998). These gases in the atmosphere absorb infrared radiation, resulting in an effect similar to that of a greenhouse for retaining internal heat (Moran and Morgan, 1997). The greenhouse effect is a natural mechanism that is necessary for life on earth because it raises the earth's temperature to a habitable level. Anthropogenic emissions of greenhouse gases result mainly from fossil fuel burning, e.g., generation of electricity and the transportation and industrial sectors (EC, 1999b). In addition, greenhouse gases are emitted as a result of natural processes, such as plant respiration, animal respiration and digestion, plant respiration, evapotranspiration, and the decay of biomass.

The amount of CO_2 in the atmosphere is steadily increasing as a result of humans burning fossil fuels (Trefil, 1999). Large increases in the concentrations of greenhouse gases can alter the earth's radiation balance by trapping more terrestrial infrared radiation, causing more energy to be converted into thermal energy in the troposphere (Finlayson-Pitts and Pitts, 2000). Scientists are trying to assess whether human enhancement of the greenhouse effect could change the earth's climate. According to Khandekar (2000), no studies have directly and unequivocally linked increased greenhouse gas concentrations to recent increases in the global mean surface temperature. However, according to the Intergovernmental Panel on Climate Change (IPCC), the balance of evidence examined does suggest a discernible human influence on climate (IPCC, 1996).

The El Niño Southern Oscillation (ENSO) produces episodes of unusually high sea-surface temperatures in the equatorial eastern Pacific (Moran and Morgan, 1997). These episodes are associated with large-scale fluctuations in surface air pressure differential between the western and eastern tropical Pacific which, in turn, result in atmospheric oscillations. Khandekar (2000) states that large-scale atmospheric oscillations, which also include the North Atlantic Oscillation and the Arctic Oscillation, can explain part of the observed increase in the mean surface temperature of earth. The ENSO phenomenon has contributed to positive surface temperature anomalies over western Canada and the northwestern United States (Khandekar, 2000).

2.2 Model Estimates of Temperature

In attempts to simulate future climate, models are employed based on what is known of the processes influencing the earth's climate. Global climate models or general circulation models (GCMs) are three-dimensional numerical models consisting of mathematical relationships that

approximate how the atmospheric system works in nature (Moran and Morgan, 1997). GCMs use grids to partition the atmosphere into cells, and variables such as temperature and humidity, are computed for each cell. One variable involved in climate modelling is the CO_2 concentration in the atmosphere. Models have been used to simulate the atmosphere and predict future climate as atmospheric concentrations of CO_2 increase. GCMs estimate that by 2050, global warming due to the greenhouse effect will be 1.5°C – 4.5°C, with the most pronounced changes taking place in northern latitudes (Gan, 1998).

It is important to note, however, that models are abstractions that represent only what are considered to be the major aspects of climate-related processes. Some limitations of GCMs include their inaccuracy in simulating the role of clouds and oceans in climate variation (Moran and Morgan, 1997), as well as inadequate simulation of sea ice cover and sea ice thickness in coupled climate models (Khandekar, 2000). More importantly, the limited spatial resolution of GCMs greatly limits climate prediction on local or regional scales. The number of GCM grid points is limited by the data capacity and speed of modern supercomputers. It is obvious that computers cannot hold sufficient data to represent every point on the earth, nor every level of the atmosphere. The GCM output used for this study came from a GCM with a surface grid resolution of roughly 3.7° latitude by 3.7° longitude. This resolution is not sufficiently high for GCM results to effectively represent smaller areas, such as Alberta (Wong et al., 1989).

Besides modelling, another approach to climate forecasting is to take past climate trends and extrapolate them into the future, using what we know of factors that have contributed to past climatic variation. However, no analogues of human-induced global warming have been found from the statistically significant changes identified in the climatic record (Moran and Morgan, 1997).

3.0 DATA AND ANALYSIS METHODS

Temperature data used for this study of Alberta were derived from two different sources. Observational temperature data came from measurements taken at climate stations across Alberta and simulated temperature data were obtained from global climate model (GCM) outputs. Trends calculated from both data sources are compared in section 4.3.

3.1 Observational Data

The observational data set for this study consisted of rehabilitated historical temperature data provided by Environment Canada at Downsview, Ontario. It is well known that most long-term climate data sets contain variations due to nonclimatic factors, such as site relocations, instrument changes, and changes in observing procedures (Vincent, 1997). To address this concern, the Canadian Historical Temperature Database (CHTD) was created in order to provide a long-term, complete, and homogeneous monthly temperature series suitable for use in climate change analyses in Canada (Vincent, 1999).

Alberta data from the CHTD included 25 stations, each having average monthly and average annual mean, minimum, and maximum temperatures. A plot of the study area was previously given in Figure 1.1 and the locations and periods of data for each station were given in Table 1.1. The stations had varying data periods within the 1895–1995 period; therefore to provide comparability among the 25 stations, a common time period of 1938–1995 (inclusive) was used. Consequently, 58 years of observational temperature data were available for use in the temperature trend analysis. In later sections, a shorter time period of 1960–1995 (inclusive) is explored for comparison of the magnitude of warming in Alberta over the two different periods.

3.2 Methods for Analysis of Observational Data

The observational temperature data were analyzed by station. A linear regression analysis was performed to identify annual and monthly trends in the mean, minimum, and maximum temperature at each Alberta climate station. This analysis provides a best-fit straight line through the data to estimate the trend. Following this, the trends were tested for statistical significance, with consideration for autocorrelation, according to the details given in Appendix I.

The average of all 25 climate stations was also taken to give one Alberta average for mean, minimum, and maximum, temperatures. A single Alberta value from the observational data was required so that a comparison could be made with the GCM results, which were averaged into one Alberta value. It is recognized that this type of uniform average (arithmetic mean) may be biased due to the uneven distribution of stations.

Another, probably more accurate, averaging method is called optimal averaging. An optimal average is a weighted average that considers the spatial distribution of climate stations. A study by Shen (1999), which investigated temperature change in Alberta by applying both uniform averages and optimal averages, found that optimal averaging provided more conservative estimates of temperature trends in Alberta than uniform averaging.

3.2.1 Method of Plotting Temperature Trends

The calculated mean, minimum, and maximum temperature trends were plotted on maps of Alberta in order to examine the spatial variation of temperature trends across the province. Trends calculated for each station were gridded using the Kriging method (see Appendix I). This process, which is incorporated in the contour mapping software, generates a grid of evenly distributed trend data points covering the entire Alberta plot. The contour maps produced gave a spatial representation of temperature trends in Alberta and were used to identify whether particular regions of Alberta experienced more warming than others over the past 4–6 decades.

3.3 GCM Output

The GCM outputs were downloaded from the Canadian Centre for Climate Modelling and Analysis online (CCCma, 1999). The simulations were performed by the first-version Canadian Global Coupled Model (CGCMI). The CGCMI includes an atmospheric component derived from the previous model (the second-generation atmospheric GCM), which is coupled with an ocean component and a heat and water flux adjustment from uncoupled atmosphere and ocean model runs (CCCma, 1999). The CGCMI simulations also consider greenhouse gas forcing and the direct effect of sulphate aerosols. More information on this and other climate models developed by the CCCma can be found on their website at http://www.cccma.bc.ec.gc.ca/models/models.html.

A total of 201 years of data were obtained from the GCM, covering 1900–2100. Within this time period, the CCCma (1999) identifies some general climatic periods:

1900–1920 :	"pre-industrial" climate
1975–1995 :	present climate
2040–2060 :	approx. CO_2 doubling
2080–2100 :	approx. CO_2 tripling

3.3.1 Output Format

The GCM outputs included annual mean, minimum, and maximum temperatures from each of three model runs:

❶ Control – a control simulation using present-day atmospheric greenhouse gas concentrations

❷ GHG – a transient simulation (with gradually increasing CO_2) in which the atmospheric concentration of greenhouse gases (GHG) corresponds to that observed from 1900 to present and increases at a rate of 1% per year thereafter until the year 2100

❸ GHG+A – a transient simulation in which the atmospheric concentration of greenhouse gases (GHG) corresponds to that observed from 1900 to present and increases at a rate of 1% per year thereafter until the year 2100, and which also includes the direct effect of sulphate aerosols (A) by increasing the surface albedo

A region had to be defined for obtaining the GCM outputs, so as to include all possible grid cells in the province of Alberta. The selected region spanned from 46.39°N to 61.23°N latitude and from

112.50°W to 123.75°W longitude and included 20 grid cells in total. Only eight of these grid cells fell within the Alberta boundaries, which are 49°N to 60°N latitude and 110°W to 120°W longitude.

The CCCma (1999) cautions that, because climate models attempt to represent the full climate system on a large (global) scale, estimates of regional climate change from model results are subject to sampling variability, especially with analyses on small scales (shorter than 1000–1500 km).

3.4 Methods of Analysis of GCM Output

Twenty grid points were downloaded from the GCM, which surrounded and included the province of Alberta. The points that fell outside of Alberta were not included; only the remaining eight data points that were within the Alberta boundaries were used for analysis.

For each of the eight Alberta grid points, mean, minimum, and maximum temperatures were estimated for each of the Control, GHG, and GHG+A runs for each year from 1900 to 2100. The eight temperature values were then averaged to get single mean, minimum, and maximum values for the province, for each run, and for each year of data.

After a single mean, minimum, and maximum value was determined for each of the Control, GHG, and GHG+A runs, the value from the Control run (current climate and CO_2 levels) had to be subtracted from the GHG and GHG+A runs. The results, after subtraction, were residual mean, minimum, and maximum temperature values, which represent the estimated effects of an increase in CO_2 and/or aerosols. A linear regression was then performed on these residual values to estimate annual trends in the mean, minimum, and maximum temperatures for Alberta.

4.0 ANNUAL TEMPERATURE TRENDS

Although average global temperatures have shown a general warming trend from the late 1800s on, the increase in surface temperatures has not been continuous. Cooling during the 1940–1970 period interrupted the gradual warming trend in the middle and high latitudes of the northern hemisphere (Moran and Morgan, 1997). Warming has taken place from approximately 1910 to 1940 and from 1975 to the present, with recent years being some of the warmest since records began around 1860 (Finlayson-Pitts, and Pitts). A recent article by Environment Canada revealed that 1998 was the warmest year on record in Canada as well as globally (EC, 1999a).

4.1 Observational Data

Observational temperature data were obtained from 25 climate stations across Alberta (Figure 1.1) and the common period of 1938–1995 was used for analyzing trends. Trends in mean, minimum, and maximum temperatures were investigated over this entire data period, as well as over a shorter period, 1960–1995. Temperature changes over the two periods were then compared.

4.1.1 Individual Station Comparisons

The observed mean, minimum, and maximum temperature trends at Alberta climate stations were compared. The locations of these 25 stations were shown in Figure 1.1. Trends were calculated over the 1938–1995 period (the common data record for all stations) as well as over a shorter time period, 1960–1995, for each station. The statistical significance was also computed for the minimum and maximum temperature trends over both time periods. Details of the statistical analyses are given in Appendix I.

1938–1995

All climate stations in Alberta had mean warming trends over the 1938–1995 period except for Carway, which had a mean cooling trend of 0.01°C/decade. Banff had the greatest mean warming trend, 0.22°C/decade, followed by Coronation, which had a mean temperature increase of 0.17°C/decade over the same period. Figure 4.1 is a plot of mean temperature trends in Alberta, in °C/decade. The trend in the mean is listed for each station and contours are plotted based on these values using the Kriging method of gridding (described in Appendix I). This plot shows warming of the mean temperature in the south-central part of the province, with the greatest warming around Banff. The warming trend then decreases further south and becomes a cooling trend in the southwestern corner of the province, surrounding Carway.

Minimum temperatures in Alberta increased at every station during the 1938–1995 period, except at Carway, Lethbridge A, and Pincher Creek, where general cooling trends were seen instead. The greatest increase in minimum temperature was found at Banff, 0.34°C/decade. Figure 4.2 is a plot of the minimum temperature trends in Alberta, in °C/decade. Asterisks appear above the trends that were found to be significant at the 10% level. Only two of the stations had minimum warming trends that were significant at the 5% level during the 1938–1995 period, and an additional three stations had significant minimum trends at the 10% level. Table AII.1 in Appendix II lists the minimum temperature trends during the 1938–1995 period at each Alberta station and identifies whether or not each trend is significant at the 10% and 5% levels.

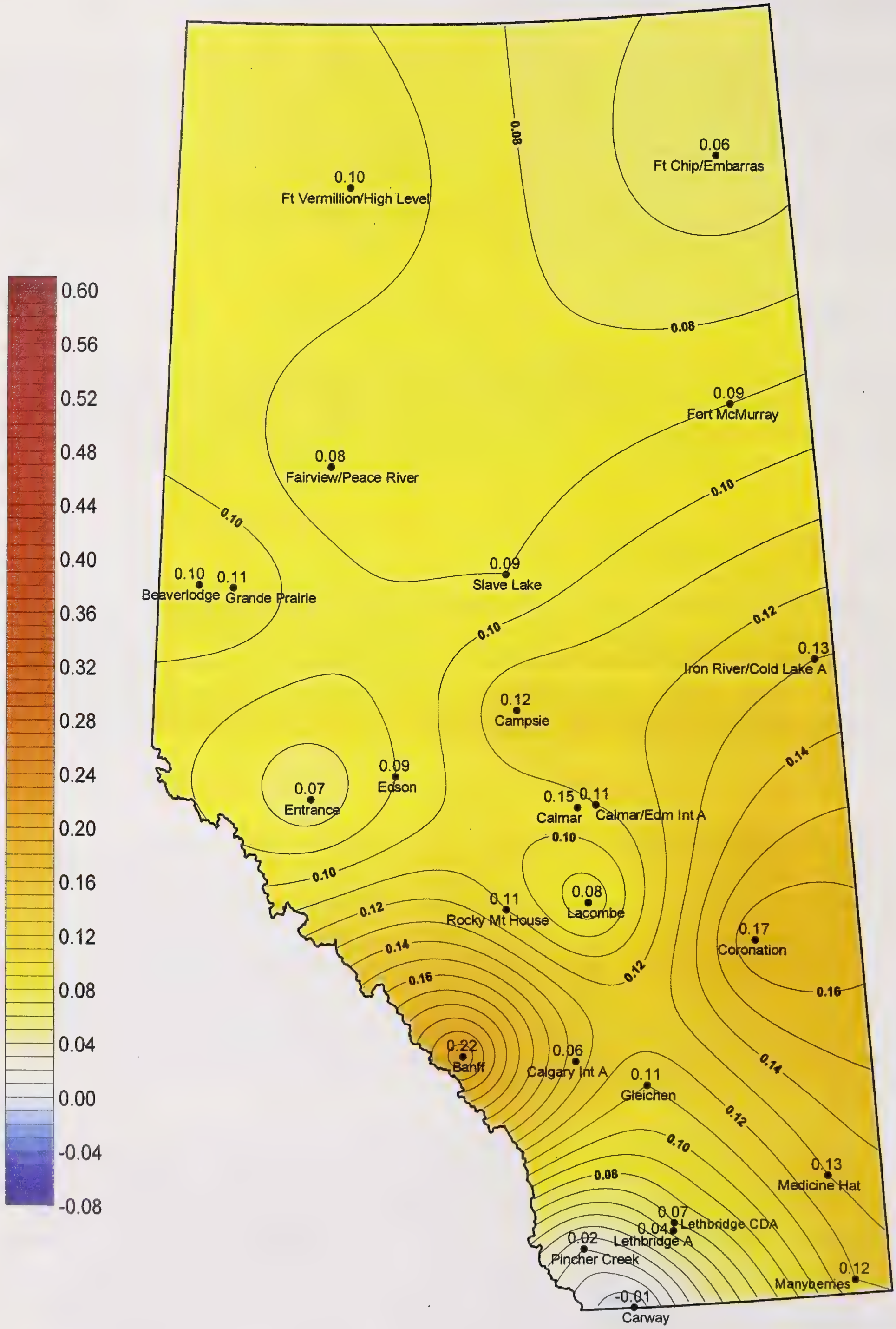


Figure 4.1 **Mean temperature trends in Alberta (°C/decade), 1938–1995**

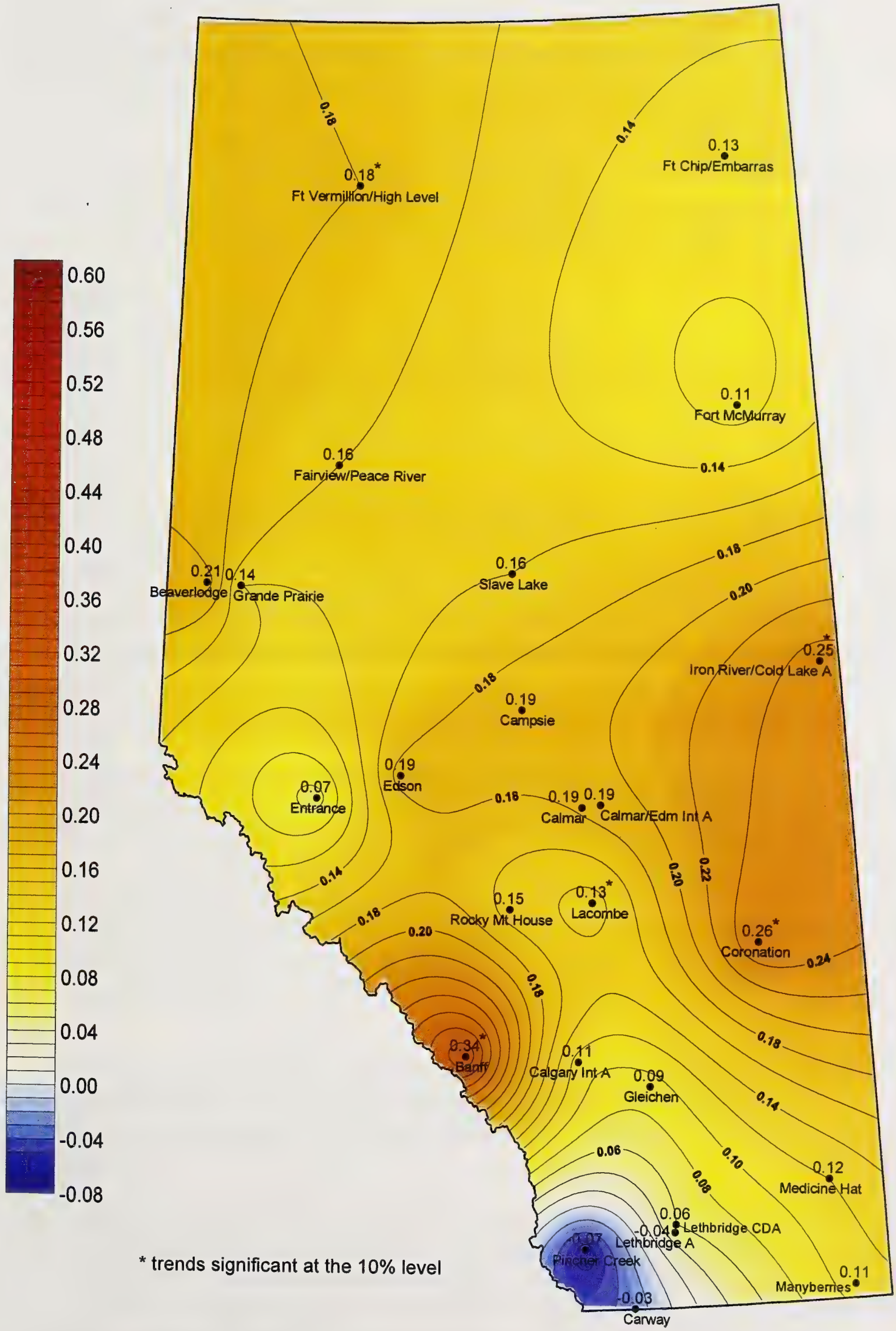


Figure 4.2 Minimum temperature trends in Alberta (°C/decade), 1938–1995

Figure 4.2 shows two distinct areas of increased minimum temperature, one surrounding Banff and the other on the eastern side of the province, surrounding Coronation and Iron River/Cold Lake Airport. Lowering of the minimum is apparent in the southwestern corner of the province, around Pincher Creek.

There was less increase in annual maximum temperatures in Alberta than in the annual minimum temperatures. The trends in maximum temperature are displayed in Figure 4.3. This plot shows the largest warming trends in the southeastern corner of the province, with cooling trends in the northern region.

The greatest increasing trend in maximum temperature over the 1938–1995 period was observed at Medicine Hat, where the maximum temperature increased 0.14°C/decade. However, as Table AII.1 shows, none of the trends in maximum temperature were statistically significant at the 10% level over the 1938–1995 period. Decreasing trends in the maximum were calculated for Beaverlodge, Edson, Fairview/Peace River, and Fort Chipewyan/Embarras over the 1938–1995 period.

In general, over the 1938–1995 period, minimum temperatures increased more than maximum temperatures in Alberta. It has been suggested that urbanization and the resulting increase in humidity and cloud cover tends to increase the minimum temperature more than the maximum (Khandekar, 2000). The greatest increasing trend was 0.34°C/decade, seen in the minimum temperature at Banff. However, the greatest decreasing trend was also seen in the minimum temperature, at Pincher Creek, where the minimum temperature decreased at an average rate of 0.07°C/decade during the 1938–1995 period.

1960–1995

Mean temperatures increased at every station in Alberta over the 1960–1995 period. The mean warming trends calculated over this period exceeded those calculated over the entire time period of 1938–1995. The stations that had the greatest mean warming over the 35-year period (1960–1995) were Beaverlodge, where the mean temperature increased 0.56°C/decade, and Slave Lake, which saw mean warming of 0.51°C/decade. No Alberta climate stations had mean cooling trends over this period. The calculated trends in the mean temperature are shown in Figure 4.4, along with contours to give the general spatial variability of the mean temperature trends. This plot reveals the area of greatest warming in the north-central part of the province, surrounding Beaverlodge and Slave Lake and extending to Fort Chipewyan/Embarras.

Minimum temperatures in Alberta have generally increased over the 1960–1995 period at every climate station. Slave Lake had the greatest rate of increase in minimum temperature of all Alberta stations, 0.58°C/decade. No Alberta stations had decreasing trends in minimum temperature over the 1960–1995 period.

Minimum temperature trends over the 1960–1995 period are shown in Figure 4.5 in °C/decade. The trends that are significant at the 10% level are denoted on the plot by asterisks above the trend values. Of the 25 trends in minimum temperature, 16 were statistically significant at the 5% level and an additional 3 were significant at the 10% level. A list of the trends over the 1960–1995 period, indicating which are significant at the 10% and 5% levels, is given in Table AII.2 in Appendix II. The area of greatest increase of minimum temperature occurred in the north-central part of the province, and the smallest increases were observed in the northwestern and southwestern corners.

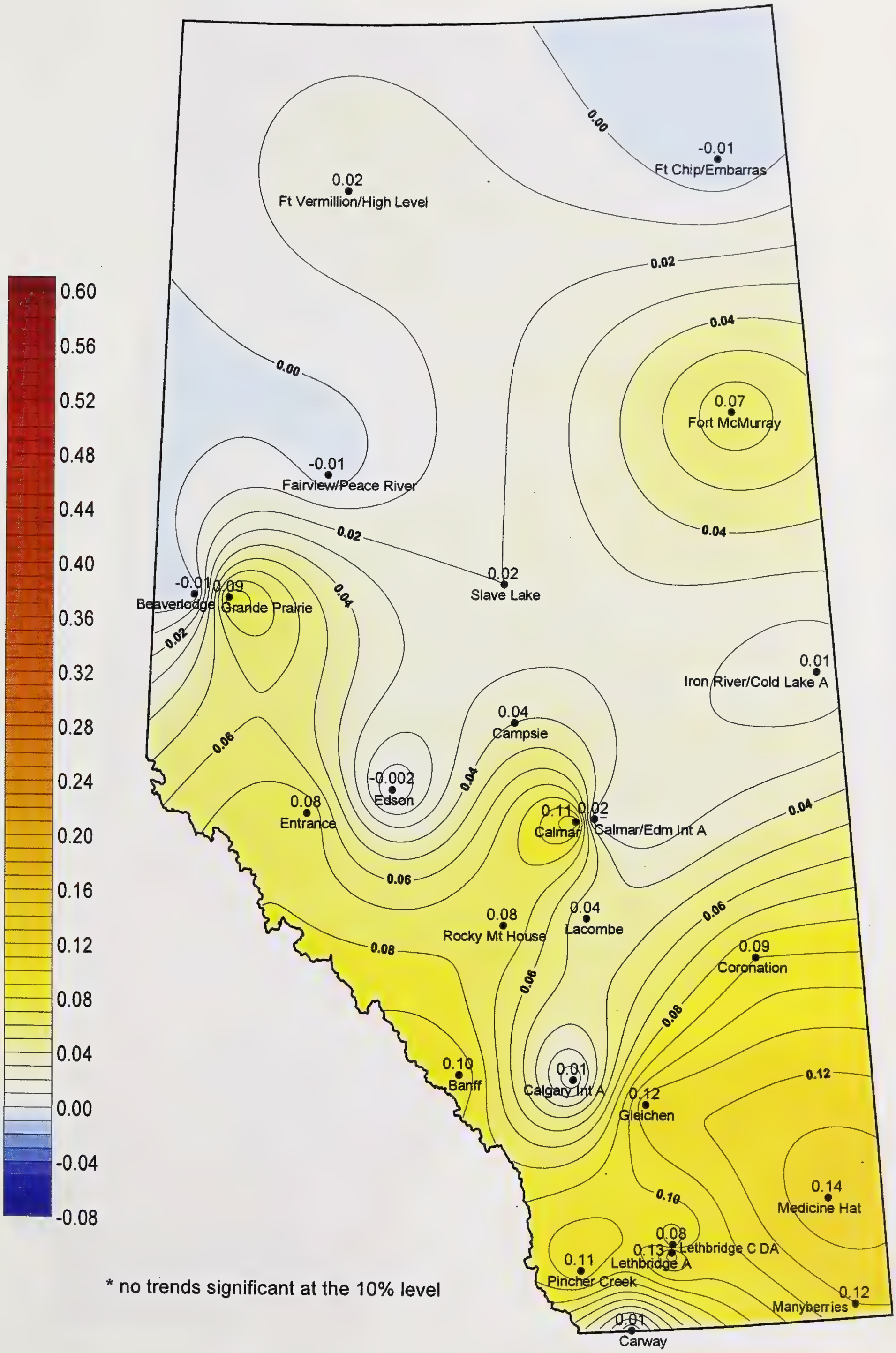


Figure 4.3 **Maximum temperature trends in Alberta (°C/decade), 1938–1995**

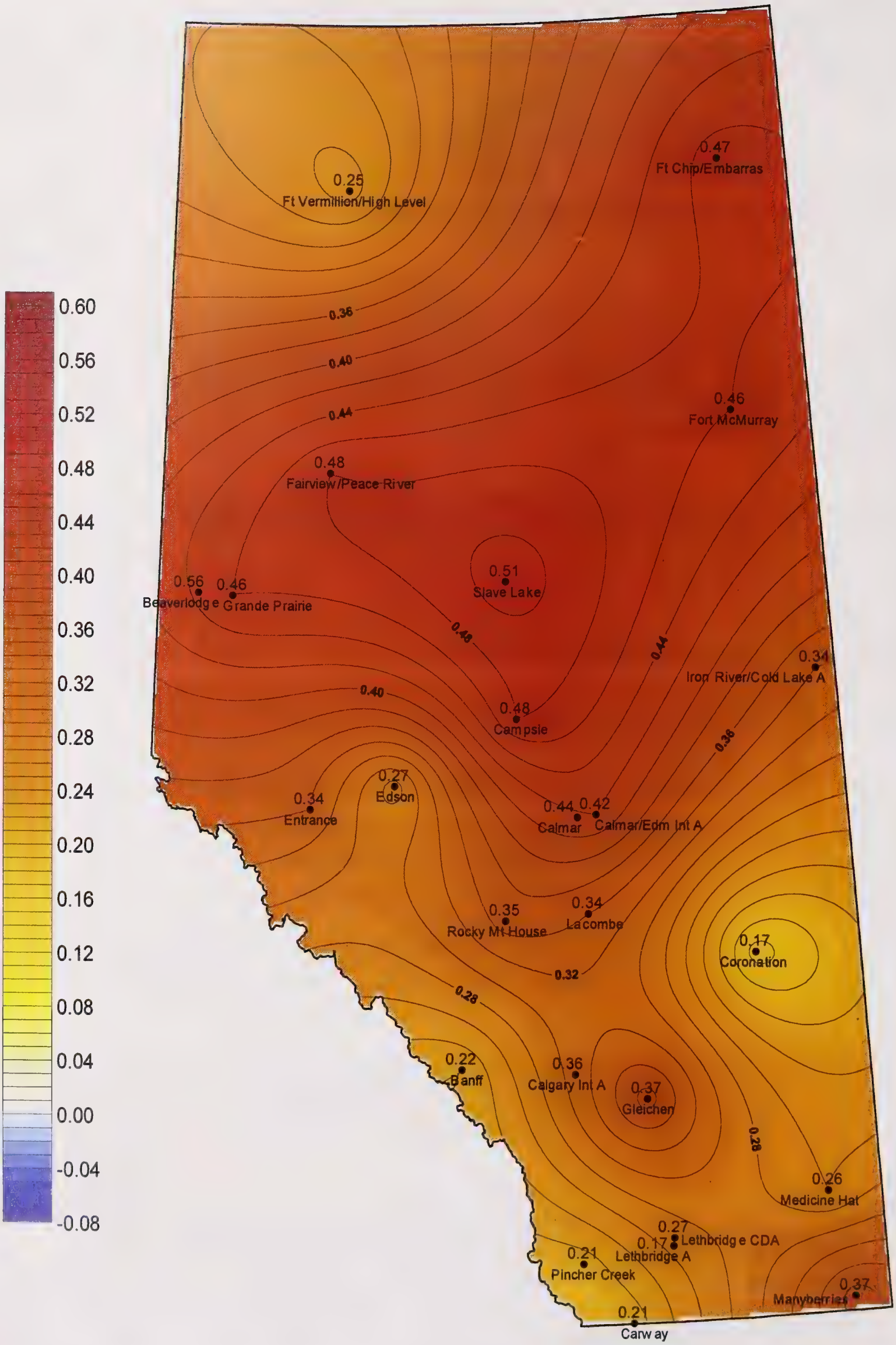
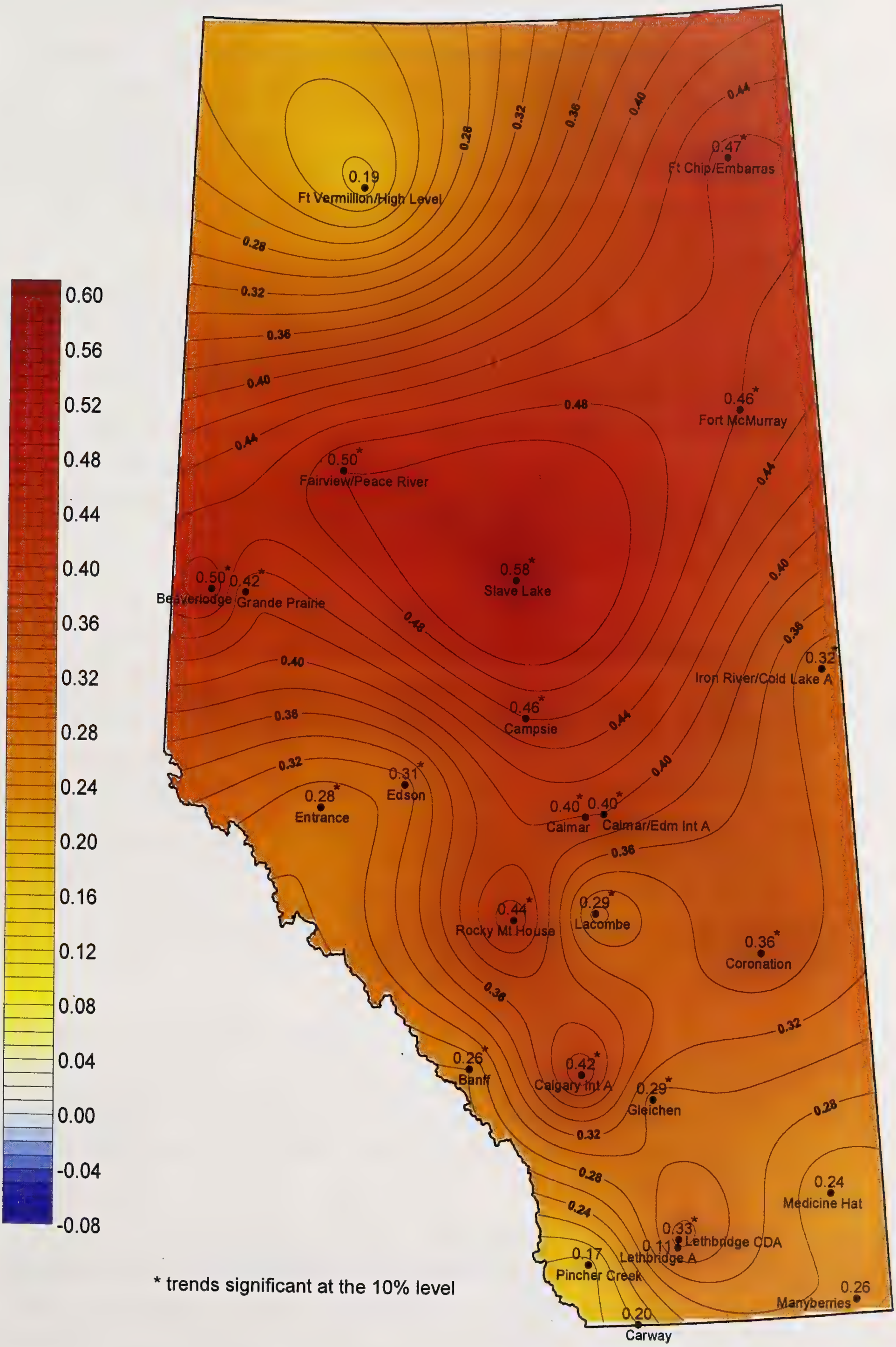


Figure 4.4 **Mean temperature trends in Alberta (°C/decade), 1960–1995**



* trends significant at the 10% level

Figure 4.5 Minimum temperature trends in Alberta (°C/decade), 1960–1995

All climate stations in Alberta recorded increasing trends in maximum temperature over the 1960–1995 period. Maximum temperatures over the 36 years generally increased at a greater rate than minimum temperatures over the same period. The greatest increase in maximum temperature during the 1960–1995 period was found in Beaverlodge, where the maximum increased 0.62°C/decade on average. Figure 4.6 shows the spatial variation of maximum temperature trends between 1960 and 1995. Asterisks on the plot denote trends that are statistically significant at the 10% level. As Table AII.2 shows, 10 of the 25 maximum temperature trends were significant at the 5% level and an additional 5 were significant at the 10% level. The greatest warming in the maximum occurred in northwestern Alberta, around Beaverlodge.

During the 1960–1995 period, the increase in maximum temperature was slightly greater than the increase in minimum temperature. However, both the minimum and maximum trends during this period were larger than minimum and maximum trends over the entire period from 1938 to 1995. There were more statistically significant minimum trends than maximum trends, but there were also many more significant trends over the more recent time period than over the longer one. Overall, increases were greater and trends were more significant during the 1960–1995 period than the 1938–1995 period. Table 4.1 contrasts the mean, minimum, and maximum temperature trends, in °C/decade, over both time periods and Figure 4.7 gives a graphic comparison of the mean temperature trends during the two periods.

4.1.2 Average Temperature Trends in Alberta

The mean, minimum and maximum temperature trends at all 25 Alberta climate stations were averaged to give general trends for the province of Alberta. This form of averaging, called an arithmetic mean, applies an equal weighting to each station. An Alberta average was required in order to perform comparisons with the GCM data trends, which are for the entire province of Alberta. However, since the climate stations are not evenly distributed, error is introduced by using an arithmetic mean because some stations are thereby assumed to represent greater areas than others. Taking a weighted average may have been more appropriate, as it adjusts for uneven distribution of stations; however, in order to simplify calculations, this averaging method was not investigated here. The Alberta climate stations are from a variety of eco-regions across the province, therefore more emphasis was put on individual station analysis. Nonetheless, the spatial averaging was used, but only to compare to the trends simulated by GCM outputs.

1938–1995

During the 1938–1995 period, a mean warming trend of 0.1°C/decade was calculated using observational data from the Alberta climate stations. Based on this rate of increase, average temperature in Alberta underwent a general temperature increase of approximately 0.6°C over the 58-year period, for an approximate warming rate for Alberta of 1.0°C/century. This result is similar to the results of Wong et al. (1989), who found that the average warming in Alberta was 1.3°C/century, based on data from 1951–1987.

The average minimum temperature in Alberta increased more than the average maximum temperature over the 1938–1995 period. The average minimum temperature in Alberta increased at a rate of 0.14°C/decade, giving a total of 0.8°C over the 58-year period. The average calculated increase in maximum temperature was 0.06°C/decade, for a total warming of 0.3°C over the 58 years. Therefore, the increase in the average minimum temperature over Alberta was approximately three times the increase in the average maximum temperature.

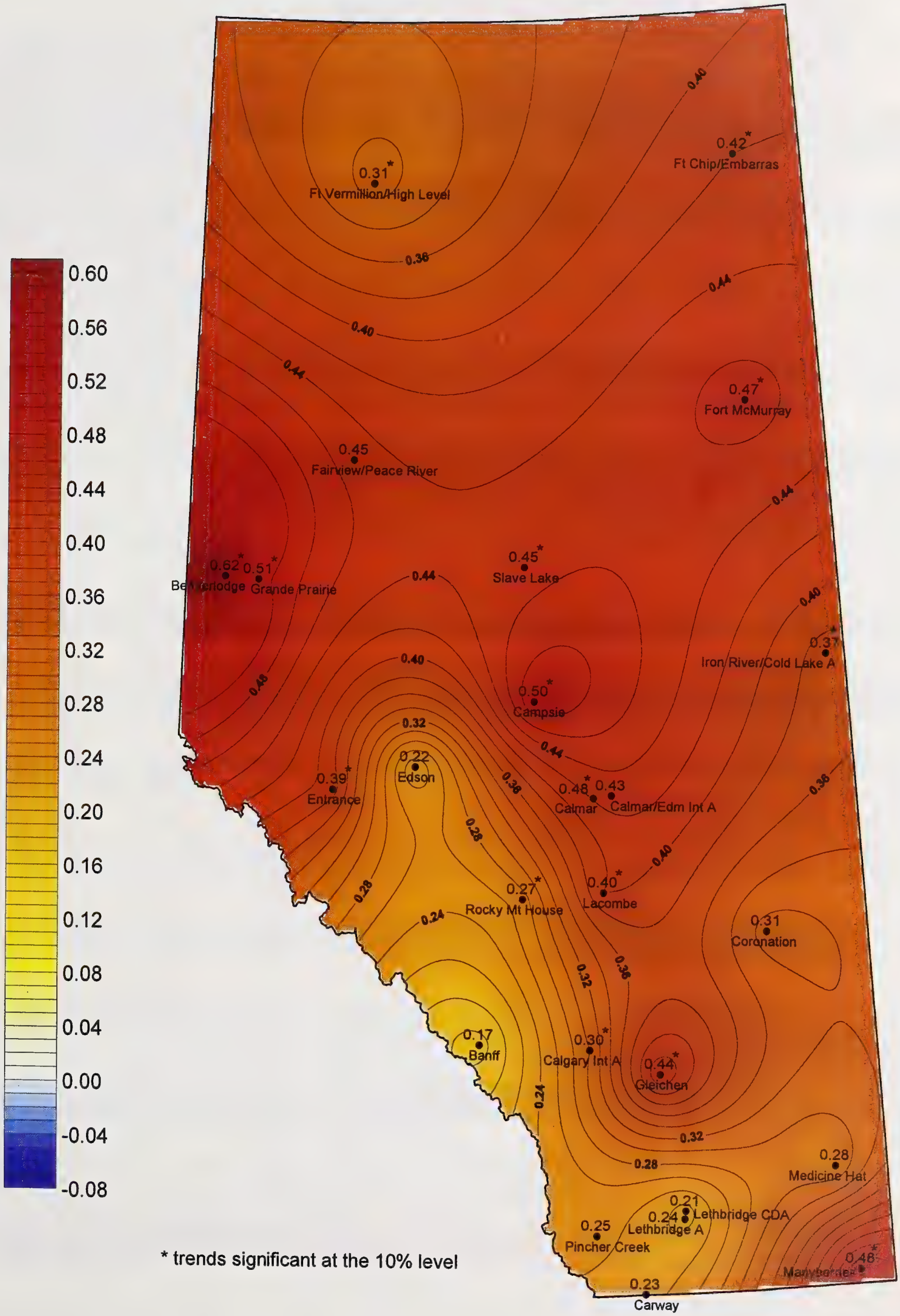


Figure 4.6 Maximum temperature trends in Alberta (°C/decade), 1960–1995

Table 4.1 **Temperature trends observed at Alberta climate stations, 1938–1995 and 1960–1995**

	1938 – 1995 °C/decade			1960 – 1995 °C/decade		
Station	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Banff	0.22	0.34	0.10	0.22	0.26	0.17
Beaverlodge CDA	0.10	0.21	-0.01	0.56	0.50	0.62
Calgary Int A	0.06	0.11	0.01	0.36	0.42	0.30
Calmar	0.15	0.19	0.11	0.44	0.40	0.48
Calmar / Edmonton Int A	0.11	0.19	0.02	0.42	0.40	0.43
Campsie	0.12	0.19	0.04	0.48	0.46	0.50
Carway	-0.009	-0.03	0.01	0.21	0.20	0.23
Coronation / Coronation A	0.17	0.26	0.09	0.31	0.36	0.26
Edson / Edson / Edson A	0.09	0.19	-0.002	0.27	0.31	0.22
Entrance	0.07	0.07	0.08	0.34	0.28	0.39
Fairview / Peace River A	0.08	0.16	-0.006	0.48	0.50	0.45
Fort Chipewyan / Embarras A / Fort Chipewyan A	0.06	0.13	-0.01	0.45	0.47	0.42
Fort McMurray / Fort McMurray A	0.09	0.11	0.07	0.46	0.46	0.47
Fort Vermilion CDA / High Level A	0.10	0.18	0.02	0.25	0.19	0.31
Gleichen	0.11	0.09	0.12	0.37	0.29	0.44
Grande Prairie / Grande Prairie A	0.11	0.14	0.09	0.46	0.42	0.51
Iron River / Cold Lake A	0.13	0.25	0.01	0.34	0.32	0.37
Lacombe CDA	0.08	0.13	0.04	0.34	0.29	0.40
Lethbridge A	0.04	-0.04	0.13	0.17	0.11	0.24
Lethbridge / Lethbridge CDA	0.07	0.06	0.08	0.27	0.33	0.21
Manyberries CDA	0.12	0.11	0.12	0.37	0.26	0.48
Medicine Hat A	0.13	0.12	0.14	0.26	0.24	0.28
Pincher Creek Town / Pincher Creek / Pincher Creek A	0.02	-0.07	0.11	0.21	0.17	0.25
Rocky M H / Rocky M H / Rocky Mt House (Aut)	0.11	0.15	0.08	0.35	0.44	0.27
Slave Lake / Slave Lake A	0.09	0.16	0.02	0.51	0.58	0.45
Averages	0.10	0.14	0.06	0.36	0.35	0.37

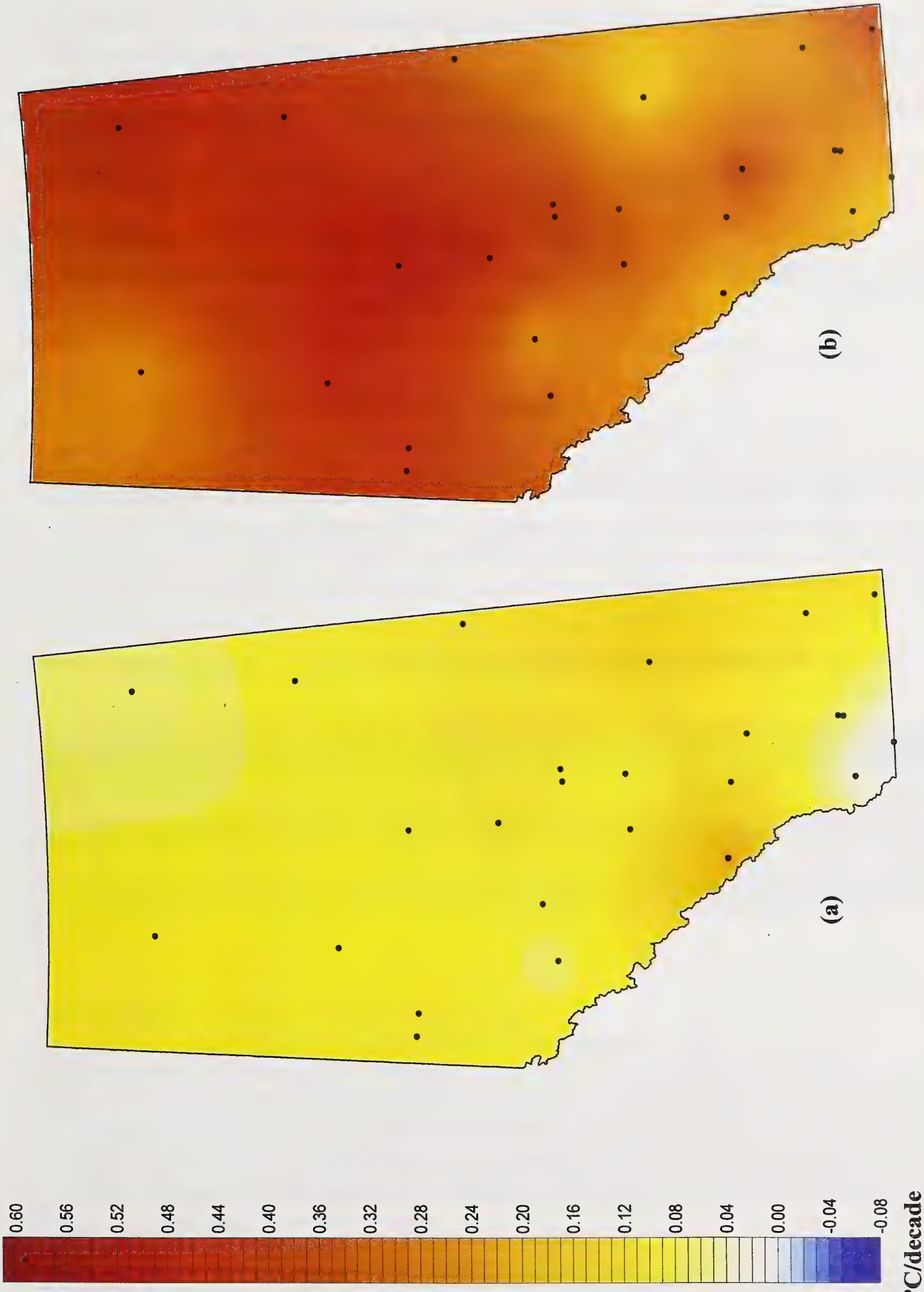


Figure 4.7 Comparison of mean temperature trends (a) 1938–1995, and (b) 1960–1995

Shen (1999), who used optimal averages, also found an upward trend in the minimum temperature of approximately 0.8°C in Alberta since 1920. Likewise, Karl et al. (1993) found that the increase in the minimum global temperature has been three times the increase in the maximum temperature (0.84°C vs 0.28°C) for the 1951–1990 period.

1960–1995

The mean warming trend calculated for the 1960–1995 period for Alberta was 0.36°C/decade, which is approximately four times the average rate of warming over the 1938–1995 period. Therefore, the overall increase in mean temperature, averaged for all Alberta stations, was 1.3°C for the 1960–1995 period.

In contrast with the trends observed for the 1938–1995 period, the minimum and maximum temperatures increased at similar rates during the 1960–1995 period, with the maximum increasing at a rate of only 0.02°C/decade more than the minimum. The average minimum temperature increased at a rate of 0.35°C/decade over the 36-year period, while the average maximum increased 0.37°C/decade over the same period.

Therefore, using the shorter, more recent 1960–1995 period for the analysis gave greater average warming rates for the province of Alberta than when the entire 1938–1995 period was used. Table 4.2 gives the rates of change of the mean, minimum, and maximum temperatures for both time periods, averaged for all Alberta stations.

Table 4.2 Average rates of temperature change observed in Alberta, 1938–1995 and 1960–1995

	Mean		*Min*		*Max*	
	1938 - 1995	*1960 - 1995*	*1938 - 1995*	*1960 - 1995*	*1938 - 1995*	*1960 - 1995*
°C/decade	0.10	0.36	0.14	0.35	0.06	0.37
°C over period	0.6	1.3	0.8	1.2	0.3	1.3
°C/century	1.0	1.0	1.4	1.0	0.6	1.1

4.2 GCM Output

The GCM output indicated a general warming trend in Alberta from 1900 to 2100 for both the greenhouse gas (GHG) run and the greenhouse gas plus aerosol (GHG+A) run. Over the 200 years, the GHG run estimated a greater increase in mean temperature than did the GHG+A run. This was expected, considering that the GHG+A run takes into account the direct forcing of sulphate aerosols, or the scatter of incoming solar radiation, which causes cooling (Finlayson-Pitts and Pitts). The GHG+A run does not include the indirect effects of aerosols or the possible warming effects of certain aerosols.

The predicted increase in mean temperature during the 1900–2100 period was 7.0°C with the GHG run and 5.3°C with the GHG+A run. Over this period, the minimum temperature was estimated to increase more than the maximum temperature. With the GHG run, the maximum was estimated to

increase 6.2°C while the minimum was estimated to increase 7.9°C. The GHG+A run, on the other hand, predicted a maximum increase of 4.6°C over the 200 years and a minimum increase of 6.1°C. These GCM results are reinforced by observations that the minimum temperature is increasing more rapidly than the maximum, in Alberta and Canada as well as on a global scale (Shen, 1999; Gan, 1998; Karl, 1993).

4.2.1 *Century Comparison*

The 1900–2100 data period was divided into centuries to compare the warming estimated for each period by the GHG and GHG+A runs. Table 4.3 below gives the trends calculated over these two time periods. Figure 4.8 gives a graphical representation of this century comparison.

Table 4.3 GCM century comparison (1900-1999 vs 2000-2100) in °C/decade

	Mean		Min		Max	
Century	*1900-1999*	*2000-2100*	*1900-1999*	*2000-2100*	*1900-1999*	*2000-2100*
GHG run	0.08	0.50	0.10	0.55	0.06	0.46
GHG+A run	0.06	0.44	0.07	0.49	0.05	0.39

The mean warming rates predicted for the 2000–2100 period by the GHG and GHG+A runs are, respectively, six and seven times the magnitude of the warming trend estimated for the previous century. The mean warming trend estimated from the GHG run, as shown in Figure 4.8b, is 0.008°C/year or 0.08°C/decade for the first century and 0.05°C/year or 0.5°C/decade for the following century. The century comparison results are similar for the GHG+A run. Similarly, the estimated increases in minimum and maximum temperatures from 2000 to 2100, shown in Figure 4.8a and c, are six to eight times the estimated increase from 1900 to 1999 for the GHG run and GHG+A runs.

4.2.2 *Simulated Trends for Shorter Time Periods*

GCM data were also examined over two shorter time periods, 1938–1995 and 1960–1995. The first period, 1938–1995, is the same 58-year period over which the observational data were analyzed. Over this period, a mean warming rate of 0.03°C/decade is estimated from the GHG run and a mean cooling trend of 0.10°C/decade is estimated from the GHG+A run. Therefore, over the entire 58-year period, the GHG run estimates a 0.2°C mean warming for Alberta and the GHG+A run estimates an overall 0.6°C mean cooling.

The period 1960–1995 was examined in order to obtain a simulation of the recent warming trend in Alberta. The 1960–1995 period was chosen because these 36 years form the latter portion of the Alberta climate station data set. A mean warming trend is estimated by both the GHG and GHG+A

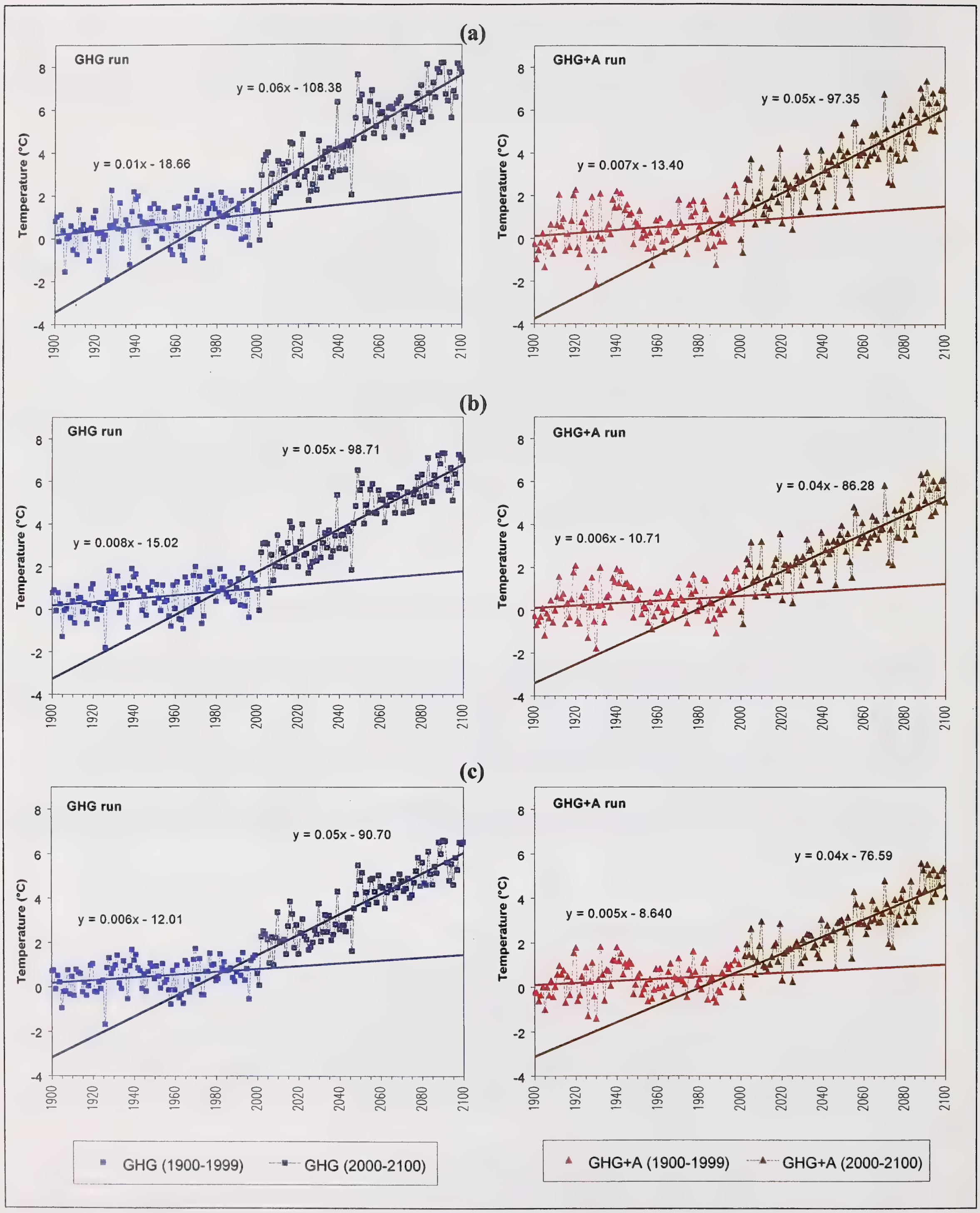


Figure 4.8 Century comparison of simulated (a) minimum, (b) mean, and (c) maximum trends

runs over this period. The GHG run estimates a mean warming of 0.19°C/decade for an overall 0.7°C increase in mean temperature over the 36 years. The GHG+A run estimates a mean warming trend of 0.05°C/decade for an overall increase in mean temperature of 0.2°C over the 36-year period.

Considering the two time periods examined, the mean warming simulated for the 1960–1995 period is four times that simulated for the 1938–1995 period by the GHG run. Similarly, the GHG+A run estimates greater warming over the shorter time period than over the longer period, by a total of 0.8°C.

Table 4.4 gives the mean, minimum, and maximum temperature trends, in °C/decade, for the three time periods examined using the GCM output. As is shown here, the longest period (1900–2100) was predicted to have the greatest warming rate, followed by the most recent period (1960–1995). The period between (1938–1995) was estimated to have the least warming. Therefore, the model forecasts that the most substantial warming in Alberta will occur following 2000.

Table 4.4 GCM temperature trends (°C/decade)

	1900 – 2100			*1938 – 1995*			*1960 – 1995*		
Run	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
GHG	0.35	0.40	0.31	0.03	0.03	0.03	0.19	0.20	0.20
GHG+A	0.27	0.31	0.23	-0.10	-0.11	-0.09	0.05	0.09	0.02

4.3 Observed Temperature Trends vs GCM Simulations

Both the GCM results and the observational data were examined over a 58-year period, 1938–1995, and a 36-year period, 1960–1995. This section compares the temperature trends estimated for Alberta by a GCM to the trends that were actually observed over these two time periods.

The last subsection (4.3.2) compares the individual trends observed at each Alberta station for the 1938–1995 and 1960–1995 periods to Alberta trends simulated by the GCM. This section evaluates how similar (or different) the individual station trends are to the GCM results.

4.3.1 Average Alberta Trends vs GCM

As stated in section 3.4, the GCM data points within Alberta were averaged to give a single temperature value for the province. General mean, minimum, and maximum GCM trends were then calculated for Alberta. Therefore, an average trend of the observational data from all Alberta stations will be used for comparisons with the trends estimated by the GHG and GHG+A runs.

1938–1995

Over the 58-year period, the GHG run estimated a 0.2°C increase in the mean temperature in Alberta. The GHG+A run, on the other hand, estimated a decrease in mean temperature of 0.6°C.

Both of the simulations gave smaller trends than the observed mean warming in Alberta, which was 0.6°C for the 1938–1995 period. Therefore, the observed mean warming over the 58 years was 0.4 degrees greater than the GHG estimation for Alberta and 1.2 degrees greater than the GHG+A estimation.

For the 1938–1995 period, the GHG output estimated an increase of 0.2°C in the minimum while the GHG+A run estimated an overall decrease in the minimum of 0.6°C. The observational data gave an overall increase of 0.8°C in the minimum temperature in Alberta over the 58 years.

For maximum temperature, the GHG run estimated overall warming of 0.2°C and the GHG+A run estimated overall cooling of 0.5°C. The actual trend observed in the maximum temperature in Alberta was an overall warming of 0.3°C over the 58 years.

By and large, the GCM simulation results were different from the temperature trends observed in Alberta for the 1938–1995 period. Both models showed less warming than was actually observed. In fact, the GHG+A run estimated overall decreases in the mean, minimum, and maximum temperatures over the 58-year period, while warming was actually observed in Alberta. However, as previously stated, GCM outputs are not recommended for small-scale analysis. Alberta does not quite meet the 1000 – 1500 km scale that has been proposed for applicability of GCM results (CCCma, 1999). Using uniform averaging, the closest GCM simulation was given by the GHG run for maximum temperature in Alberta. The estimated warming was only 0.1°C below the maximum warming actually observed. The other simulations differed from the observed trends by 0.4 – 1.4°C.

1960–1995

The GCM did not simulate the actual warming trends that were observed in Alberta over this 36-year period. The GHG run estimated a 0.7°C increase in mean temperature and the GHG+A run estimated a 0.2°C increase in mean temperature. Observational data, however, showed an overall increase in mean temperature of 1.3°C in Alberta over the 36 years.

For minimum temperature in Alberta, the GHG run estimated an overall increase of 0.7°C and the GHG+A run estimated an overall increase of 0.3°C. The overall increase in minimum temperature actually observed was greater than either of these estimates, 1.2°C over the 36 years. The GCM estimated an overall increase in the maximum temperature of 0.7°C by the GHG run and an increase of 0.06°C by the GHG+A run. Observations over Alberta revealed a 1.3°C increase in maximum temperature during the 1960–1995 period.

Overall, the GCM results were greatly different from observations at the scale of Alberta. Observed temperature trends were greater than the trends simulated by either the GHG or the GHG+A runs. Table 4.5 contrasts the simulated and observed trends over the two time periods.

Table 4.5 Comparison of the overall trends in simulated and observed temperatures (°C)

GHG run						
	Mean		*Min*		*Max*	
Time period	*1938-1995*	*1960-1995*	*1938-1995*	*1960-1995*	*1938-1995*	*1960-1995*
Predicted	0.2	0.7	0.2	0.7	0.2	0.7
Observed	0.6	1.3	0.8	1.2	0.3	1.3
Difference	0.4	0.6	0.6	0.5	0.1	0.6

GHG+A run						
	Mean		*Min*		*Max*	
Time period	*1938-1995*	*1960-1995*	*1938-1995*	*1960-1995*	*1938-1995*	*1960-1995*
Predicted	-0.6	0.2	-0.6	0.3	-0.5	0.06
Observed	0.6	1.3	0.8	1.2	0.3	1.3
Difference	1.2	1.1	1.4	0.9	0.8	1.2

The GHG results were closer to the observed temperature trends than the GHG+A results. However, the GHG+A run, which includes the direct effects of aerosols, is supposedly the improved scenario and is supposed to simulate temperature variation better than the GHG scenario (CCCma, 1999). However, Khandekar (2000) states that even as modellers try to include aerosol effects in climate models, the impacts of anthropogenic aerosols on present and future climate are still uncertain. The GCM used in this study included only the direct forcing of aerosols, which involves the scattering and absorption of solar radiation, but not the indirect forcing of aerosols, which includes enhancement of cloud cover.

The reason that the trends estimated by the GCM were smaller than the observed trends in Alberta is that uniform averages were used to compare to the GCM. Uniform averages tend to give higher estimates than optimal averages, which have been found to give lower, more accurate estimates (Shen, 1999).

4.3.2 Individual Station Trends vs GCM Results

Individual station trends were compared to the average trends estimated by the model to see whether any Alberta stations had results like the GCM results. These individual comparisons were not used for verification of the model.

When the mean, minimum, and maximum temperature trends at individual stations were compared to the GCM trends simulated for the province of Alberta, most stations were found to have trends that were larger than the trends estimated by the GCM. Table 4.6 (a and b) gives the difference between the mean, minimum, and maximum trends observed at Alberta climate stations and the overall Alberta trends estimated by the GHG(a) and GHG+A(b) runs.

The values given in Tables 4.6a and 4.6b show differences between the individual observed trends and the GCM trends over the 1938–1995 and 1960–1995 periods (in °C/decade). Positive values imply that the observed trend is larger than the simulated trend, and negative values imply that the observed trend is smaller than the GCM trend. Also included, at the bottom of the tables, are the

average differences between observed and estimated trends over each time period and for each model run.

Only three stations showed close agreement between observed and simulated trends over the longer time period (1938–1995). Calmar/Edmonton Int A, Fort Vermilion/High Level and Slave Lake had maximum trends that were within 0.004°C/decade of the trend estimated for Alberta by the GHG run over the 1938–1995 period. Only one station was in close agreement with the trend estimated by the GCM for the 1960–1995 period. Carway had a minimum temperature trend that was within 0.001°C/decade of the minimum temperature trend estimated for Alberta by the GHG run for the 1960–1995 period. These similarities between observed and simulated trends were for the GHG model. No stations had trends that were close to the trends estimated by the GHG+A run over the two time periods.

This analysis shows how different the actual observed temperature trends in Alberta are from the trends simulated by the GCM. It is apparent that GCMs are not useful for predicting temperature change at the scale of Alberta.

Table 4.6 Differences between trends in mean, minimum, and maximum temperatures observed at individual Alberta stations and the overall trends estimated for Alberta by GCM outputs

(a) amount that observed trends differ from GHG run trends

Banff	0.32	0.44	0.19	0.17	0.18	0.15
Beaverlodge CDA	0.20	0.31	0.08	0.51	0.41	0.61
Calgary Int A	0.16	0.22	0.10	0.31	0.33	0.28
Calmar	0.25	0.30	0.20	0.39	0.31	0.46
Calmar / Edmonton Int A	0.20	0.29	0.11	0.37	0.32	0.41
Campsie	0.21	0.29	0.13	0.44	0.38	0.48
Carway	0.09	0.08	0.10	0.17	0.11	0.21
Coronation / Coronation A	0.27	0.37	0.17	0.26	0.28	0.24
Edson / Edson / Edson A	0.19	0.30	0.09	0.22	0.22	0.21
Entrance	0.17	0.17	0.17	0.29	0.19	0.38
Fairview / Peace River A	0.18	0.27	0.08	0.43	0.42	0.43
Fort Chipewyan / Embarras A / Fort Chipewyan A	0.16	0.24	0.08	0.40	0.39	0.40
Fort McMurray / Fort McMurray A	0.19	0.22	0.15	0.41	0.37	0.45
Fort Vermilion CDA / High Level A	0.20	0.28	0.11	0.20	0.11	0.29
Gleichen	0.21	0.20	0.21	0.32	0.21	0.42
Grande Prairie / Grande Prairie A	0.21	0.24	0.18	0.42	0.33	0.49
Iron River / Cold Lake A	0.23	0.36	0.10	0.30	0.23	0.35
Lacombe CDA	0.18	0.23	0.13	0.30	0.20	0.38
Lethbridge A	0.14	0.06	0.21	0.13	0.03	0.22
Lethbridge / Lethbridge CDA	0.17	0.16	0.17	0.22	0.25	0.19
Manyberries CDA	0.21	0.22	0.21	0.32	0.17	0.46
Medicine Hat A	0.23	0.22	0.23	0.22	0.16	0.26
Pincher Creek Town / Pincher Creek / Pincher Creek A	0.12	0.04	0.19	0.17	0.09	0.23
Rocky M H / Rocky M H / Rocky Mt House (Aut)	0.21	0.25	0.16	0.31	0.35	0.25
Slave Lake / Slave Lake A	0.19	0.26	0.11	0.47	0.49	0.43
Average difference	0.19	0.24	0.15	0.31	0.26	0.35

Table 4.6 (continued)

(b) amount that observed trends differ from GHG+A run trends

	1938 – 1995 °C/decade			1960 – 1995 °C/decade		
Station	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Banff	0.32	0.44	0.19	0.17	0.18	0.15
Beaverlodge CDA	0.20	0.31	0.08	0.51	0.41	0.61
Calgary Int A	0.16	0.22	0.10	0.31	0.33	0.28
Calmar	0.25	0.30	0.20	0.39	0.31	0.46
Calmar / Edmonton Int A	0.20	0.29	0.11	0.37	0.32	0.41
Campsie	0.21	0.29	0.13	0.44	0.38	0.48
Carway	0.09	0.08	0.10	0.17	0.11	0.21
Coronation / Coronation A	0.27	0.37	0.17	0.26	0.28	0.24
Edson / Edson / Edson A	0.19	0.30	0.09	0.22	0.22	0.21
Entrance	0.17	0.17	0.17	0.29	0.19	0.38
Fairview / Peace River A	0.18	0.27	0.08	0.43	0.42	0.43
Fort Chipewyan / Embarras A / Fort Chipewyan A	0.16	0.24	0.08	0.40	0.39	0.40
Fort McMurray / Fort McMurray A	0.19	0.22	0.15	0.41	0.37	0.45
Fort Vermilion CDA / High Level A	0.20	0.28	0.11	0.20	0.11	0.29
Gleichen	0.21	0.20	0.21	0.32	0.21	0.42
Grande Prairie / Grande Prairie A	0.21	0.24	0.18	0.42	0.33	0.49
Iron River / Cold Lake A	0.23	0.36	0.10	0.30	0.23	0.35
Lacombe CDA	0.18	0.23	0.13	0.30	0.20	0.38
Lethbridge A	0.14	0.06	0.21	0.13	0.03	0.22
Lethbridge / Lethbridge CDA	0.17	0.16	0.17	0.22	0.25	0.19
Manyberries CDA	0.21	0.22	0.21	0.32	0.17	0.46
Medicine Hat A	0.23	0.22	0.23	0.22	0.16	0.26
Pincher Creek Town / Pincher Creek / Pincher Creek A	0.12	0.04	0.19	0.17	0.09	0.23
Rocky M H / Rocky M H / Rocky Mt House (Aut)	0.21	0.25	0.16	0.31	0.35	0.25
Slave Lake / Slave Lake A	0.19	0.26	0.11	0.47	0.49	0.43
Average difference	0.19	0.24	0.15	0.31	0.26	0.35

5.0 OBSERVED MONTHLY TEMPERATURE TRENDS

This section examines monthly trends in mean, minimum, and maximum temperatures in Alberta. The rehabilitated monthly temperature data (see section 3.1) from each of 25 climate stations were analyzed over the 1938–1995 period, the common data period for all stations. Linear regression was then applied to give trends in mean, minimum, and maximum temperatures for each month over the 58 years. The purpose of this component of the study was to determine which month(s) experienced the greatest warming (or cooling) over the study period.

Initially, monthly temperature trends were investigated at two climate stations, Banff and Carway. These particular stations were chosen because, out of all Alberta stations over the 1938–1995 period, Banff had the *greatest mean annual warming* trend and Carway had the *greatest mean annual cooling* trend.

5.1 Monthly Trends at Banff

At Banff, the greatest mean warming was found in March, a total of 3.8°C over the 1938–1995 period. The greatest minimum and maximum temperature increases at Banff (4.4°C and 3.2°C, respectively) also occurred in the month of March. The months of February and January had the next greatest warming trends. The monthly mean, minimum, and maximum temperature trends for Banff are given in Table 5.1. The greatest warming and cooling trends are highlighted, with the cooling trends having lighter shading than the warming trends.

Table 5.1 Monthly temperature trends at Banff, 1938–1995

	Banff					
	Mean		***Min***		***Max***	
	°C/decade	°C/58 y	°C/decade	°C/58 y	°C/decade	°C/58 y
Jan	0.44	2.5	0.57	3.3	0.30	1.8
Feb	0.54	3.1	0.70	4.1	0.37	2.2
Mar	0.65	3.8	0.76	4.4	0.54	3.2
Apr	0.29	1.7	0.40	2.3	0.18	1.0
May	0.21	1.2	0.36	2.1	0.05	0.3
Jun	0.36	2.1	0.40	2.3	0.32	1.9
Jul	0.05	0.3	0.28	1.6	-0.19	-1.1
Aug	0.25	1.5	0.45	2.6	0.06	0.3
Sep	0.09	0.5	0.18	1.0	-0.001	0
Oct	0.05	0.3	0.06	0.3	0.05	0.3
Nov	-0.09	-0.5	0.02	0.1	-0.19	-1.1
Dec	-0.24	-1.4	-0.16	-0.9	-0.32	-1.8

The greatest decreasing trends over the 1938–1995 period at Banff were found in December for mean, minimum, and maximum temperatures. Mean cooling was also found in November over the 58 years and a decrease in the maximum temperature also occurred in November and July.

5.2 Monthly Trends at Carway

When the monthly temperatures were analyzed for Carway, the largest mean warming was found in March. Over 1938–1995 the mean March temperature at Carway increased 3.9°C, which is similar to the mean warming that occurred at Banff in the month of March. The greatest increase in minimum and maximum temperature over the 58 years was also found in March (3.6°C and 4.1°C respectively). As was the case in Banff, the months of February and January had the next greatest warming at Carway. Table 5.2 lists the monthly mean, minimum, and maximum temperature trends observed at Carway, with the largest warming and cooling trends highlighted.

Table 5.2 Monthly temperature trends at Carway, 1938–1995

	Carway					
	Mean		***Min***		***Max***	
	°C/decade	°C/58 y	°C/decade	°C/58 y	°C/decade	°C/58 y
Jan	0.26	1.5	0.16	0.9	0.36	2.1
Feb	0.51	2.9	0.39	2.3	0.62	3.6
Mar	0.67	3.9	0.63	3.6	0.70	4.1
Apr	0.07	0.4	0.07	0.4	0.06	0.4
May	-0.02	-0.1	-0.02	-0.1	-0.01	-0.1
Jun	0.18	1.0	0.05	0.3	0.30	1.7
Jul	-0.37	-2.2	-0.27	-1.6	-0.47	-2.8
Aug	-0.25	-1.4	-0.12	-0.7	-0.37	-2.1
Sep	-0.18	-1.0	-0.23	-1.3	-0.13	-0.8
Oct	-0.26	-1.5	-0.23	-1.3	-0.29	-1.7
Nov	-0.34	-2.0	-0.32	-1.9	-0.36	-2.1
Dec	-0.39	-2.3	-0.47	-2.7	-0.31	-1.8

Over the 58-year period, cooling was found in the months of July–December at Carway. The largest decreases in the mean and minimum temperatures were found in the month of December, and the greatest monthly cooling at Carway was found in the maximum temperature during the month of July.

Therefore, Banff, which had the greatest mean annual warming in Alberta, experienced the most warming in March over the 1938–1995 period. Carway, on the other hand, underwent the greatest decrease in mean temperature, but also experienced the most warming during the month of March. In addition to both stations having the greatest warming in March, both had much the same magnitude of increase in mean temperature during March (3.8°C at Banff and 3.9°C at Carway) over the 1938–1995 period. Carway, however, had a greater decrease in mean temperature in the summer and fall months than did Banff for the same period. Overall, Carway had an overall decrease in annual mean temperature.

5.3 Alberta Station Comparisons

Following the monthly analysis for Banff and Carway, the monthly trends at the other climate stations were explored and compared in attempts to find a seasonal pattern for Alberta. The remaining 23

stations had monthly trends very similar to those at Banff and Carway. Table AIII.1 in Appendix III gives trends of monthly mean, minimum, and maximum temperatures for the 1938–1995 period at all Alberta stations. Figure 5.1 consists of 12 contour plots, one for each month of the year. These plots show the mean monthly warming (or cooling), in °C, observed over the 58 years in Alberta.

The greatest warming was most often found in March and February, with some warming also occurring in January. Zhang et al. (2000), however, report that over the 1900–1995 period, the most significant warming in western Canada is seen mostly during the spring and summer periods. In contrast, Figure 5.1 shows that the most significant warming in Alberta during the 1938–1995 period occurred during the late winter to early spring, with cooling in the summer, fall, and winter.

The greatest monthly warming in Alberta over the 1938–1995 period was found at Manyberries, where the mean temperature increase over the 58 years was 5.7°C in the month of March. The greatest increase in minimum monthly temperature at Manyberries was 5.0°C in March and the greatest increase in maximum monthly temperature was 6.4°C, also found in March. Following Manyberries, Medicine Hat had the second greatest monthly warming, with a mean temperature increase of 5.3°C over the 1938–1995 period, occurring in March. The greatest increase in minimum monthly temperature at Medicine Hat was 4.4°C in February and the greatest increase in the monthly maximum was 6.2°C, found in March.

Figure 5.2 shows the total mean temperature increase at Alberta stations for the month of March, in °C over the 1938–1995 period. From this plot, it seems that the southeastern corner of Alberta experienced the greatest mean warming during the month of March, with little mean temperature increase occurring in the northern part of the province.

The greatest monthly cooling trends were generally found in November and December, with some stations having the greatest cooling in July. The greatest monthly cooling occurred at the Fort Chipewyan/Embarras station, where a mean temperature decrease of 3.0°C was seen in the month of November over the 1938–1995 period. Over this period, the greatest decrease in the minimum monthly temperature at Fort Chipewyan/Embarras was 3.4°C in November and the greatest decrease in the monthly maximum was 2.8°C, in October. Figure 5.3 shows the total mean temperature decrease at Alberta stations during the month of November.

Of the 25 stations studied, 13 had the greatest monthly warming in the minimum temperature and 12 had the greatest monthly warming in the maximum. In spite of this, Table AIII.1 reveals that, out of all stations, the magnitude of monthly warming was generally greater for the maximum temperature than for the minimum (especially in the southern part of the province). However, because the maximum also underwent cooling in different months, and at a more substantial rate than the warming, there was greater overall annual warming in the minimum temperature, rather than in the maximum, at Alberta stations. Generally, the maximum temperature change in Alberta showed greater variability, temporally and spatially.

In general, from 1938 to 1995, warming in Alberta occurred in the months of January to May or June, with the greatest warming taking place in March. Cooling generally occurred in the months of July through December at Alberta stations, with the greatest cooling taking place in November. These results agree with the findings of a study by Gan (1998) on possible climatic trends on the Canadian prairies.

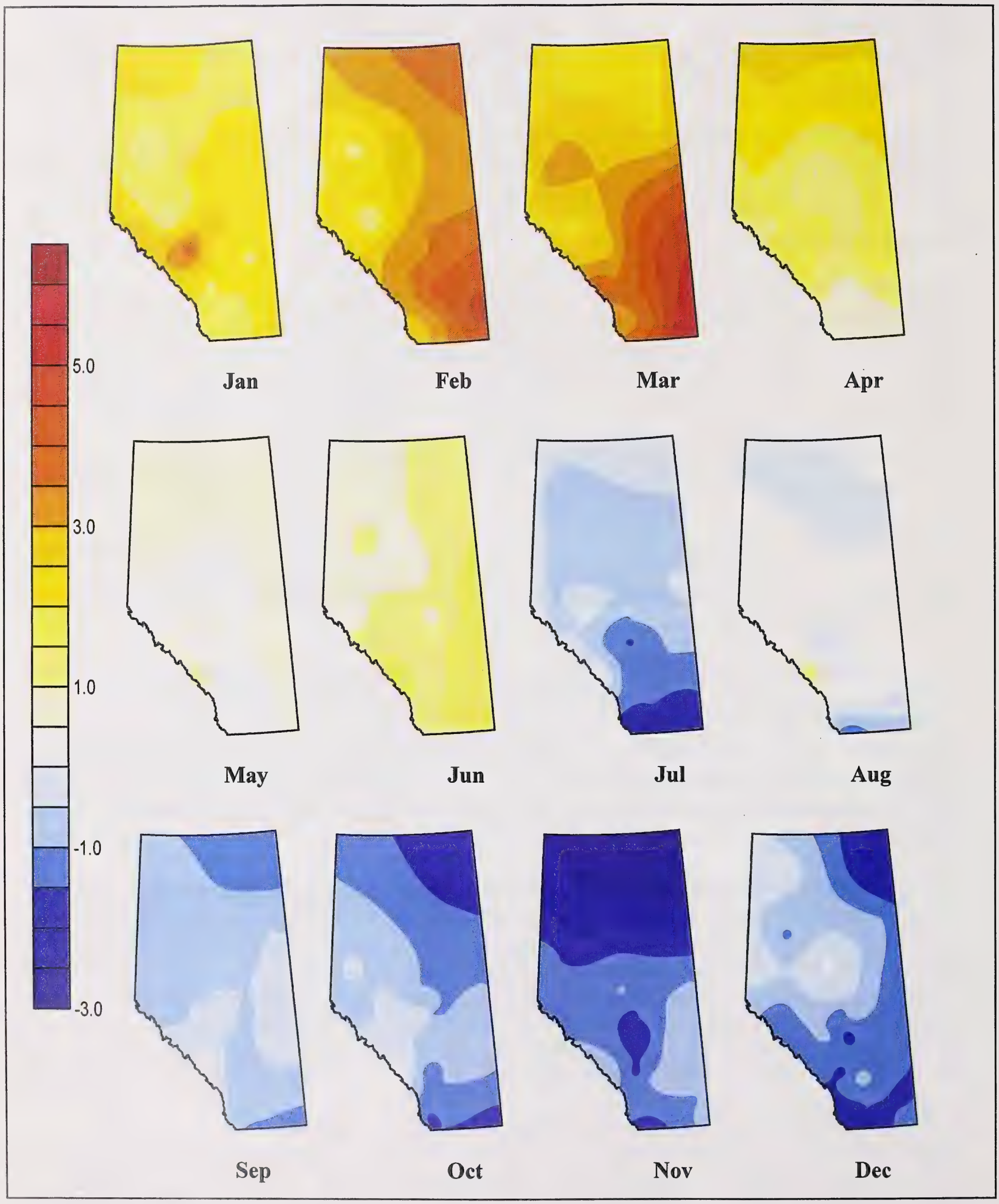


Figure 5.1 Monthly mean temperature change in °C during the 58-year period 1938–1995

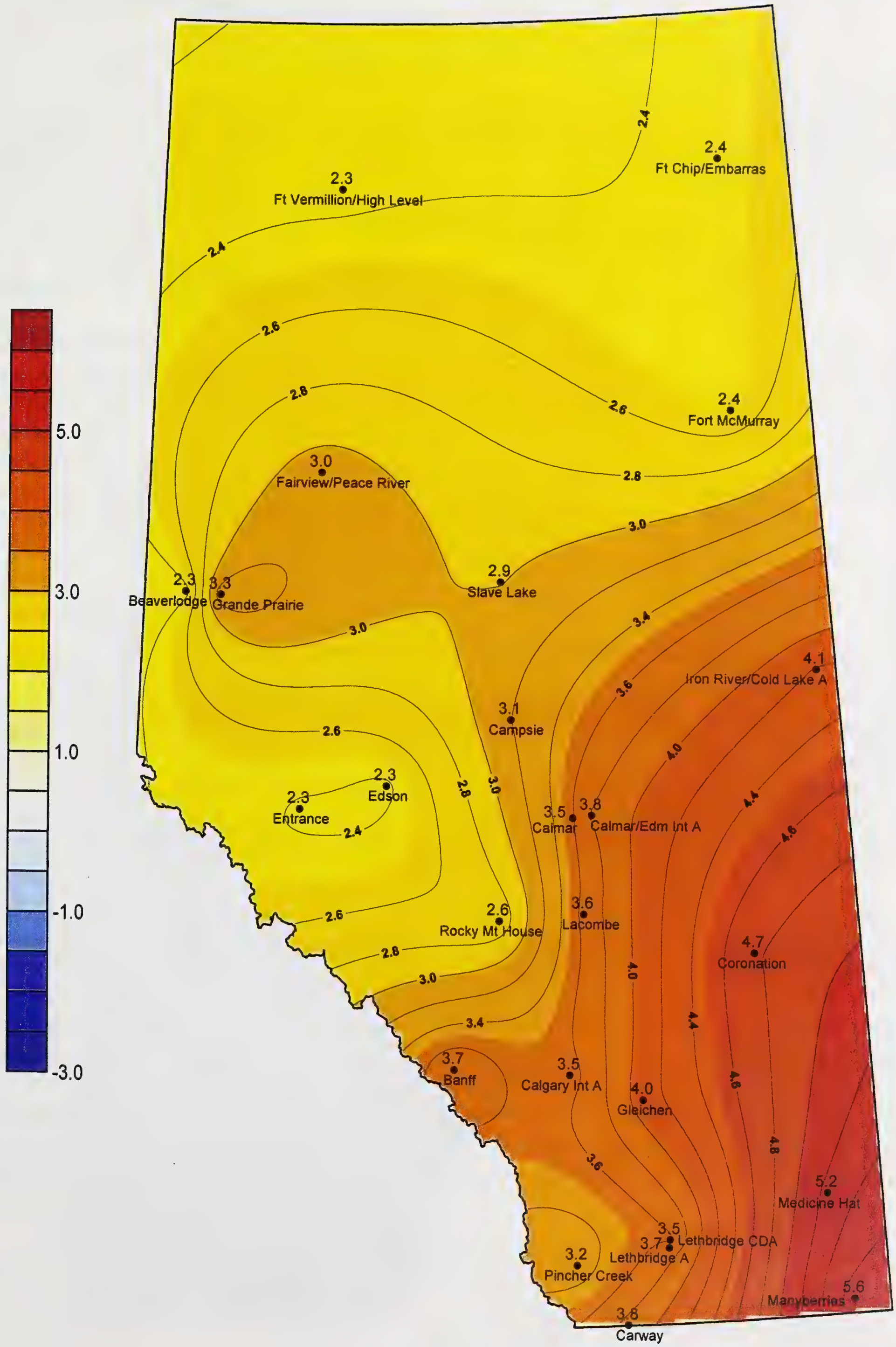


Figure 5.2 Mean temperature change in March (°C, 1938–1995)

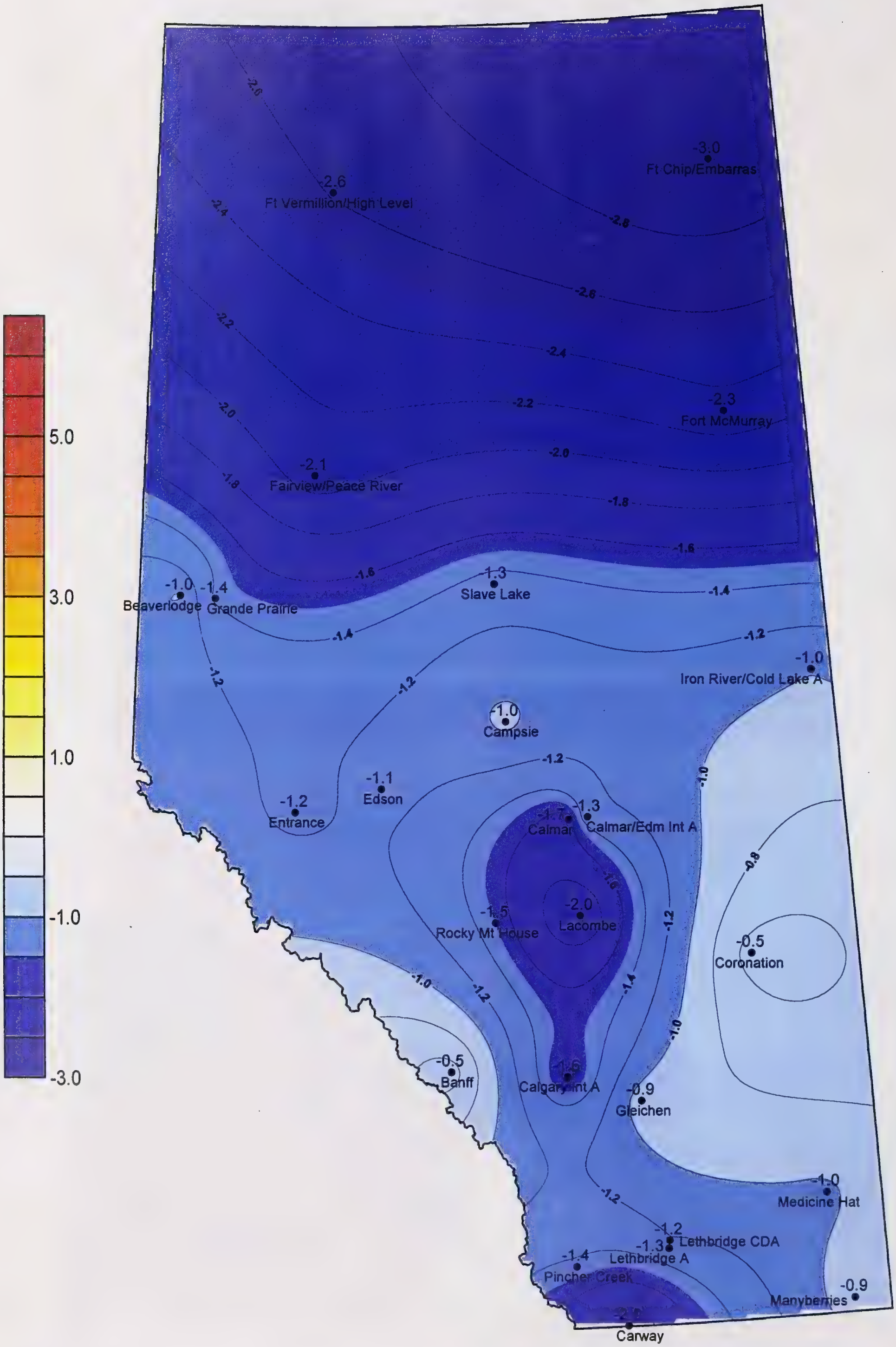


Figure 5.3 Mean temperature change in November (°C, 1938–1995)

6.0 DISCUSSION

6.1 Comparing Observed Trends at Individual Stations

There were large variations in temperature trends from station to station. This is understandable, considering the different site characteristics, such as elevation, topography, solar radiation, and distance to cities and heat sources. Pielke et al. (2000) found that the direction and magnitude of regional climate trends cannot be inferred from single-site records, even over relatively homogeneous terrain. For this reason, it is somewhat unrealistic to talk of spatial linearity and average regional warming trends for the entire province of Alberta, especially considering the non-homogeneity of the terrain.

The greatest warming trends in Alberta were found at Banff (0.22°C/decade) over the 1938–1995 period and at Beaverlodge (0.56°C/decade) over the 1960–1995 period. Banff is approximately 120 km from the nearest urban centre, Calgary, and is sheltered by the Rocky Mountains. The urban centre nearest to Beaverlodge is Grande Prairie, which has a population of about 34,000 (City of Grande Prairie, 2000). It is unlikely that proximity to urban areas contributed to the warming observed at either station. The causes of the warming at Banff during the 1938–1995 period and at Beaverlodge during the 1960–1995 period are unknown.

6.2 Minimum vs Maximum Trends

Minimum temperature in Alberta increased more than maximum temperature during the 1938–1995 period. Given that the minimum generally represents night-time temperature (Zhang et al., 2000), the differential warming of the minimum may be attributed to an increase in cloud cover at night, which reduces the release of infrared radiation. Zhang et al. (2000) report that the greater increase of the minimum in Canada coincides with a large increase in total cloud cover in Canadian mid-latitudes during the first half of the 20th century. Conversely, over the shorter 1960–1995 time period, the minimum and maximum temperature increases were comparable, with the maximum increasing at a rate of only 0.02°C/decade more than the minimum temperature.

Whether the differential increases of minimum and maximum temperatures in Alberta has been a result of natural mechanisms or human-induced effects is not certain. Karl et al. (1993) define some climatic variables that differentially affect minimum and maximum temperature: snow cover, relative humidity, cloudiness, wind speed, solar radiation, and day-to-day temperature changes (largely controlled by thermal advection). As none of these variables was considered in the study, future work could include investigating these and other climatic variables to find possible causes for the warming in Alberta. On a global scale, differential changes in daily maximum and minimum temperatures are associated with a narrowing of the diurnal temperature range, and this appears to provide at least a partial explanation for the increase in global mean temperature (Khandekar, 2000).

6.3 Trend Significance

The number of stations that had statistically significant temperature trends was strongly dictated by the time period and whether it was minimum and maximum temperature trends. More trends were significant over the, shorter more recent time period (1960–1995) than over 1938–1995. In addition, more minimum temperature trends were significant than maximum trends in Alberta. Gan (1998) also found that at stations over the Canadian prairies, more minimum temperature trends were significant than maximum temperature trends.

6.4 Monthly Temperature Trends

Warming was found in the months of January to June, with the greatest warming in March. Cooling occurred in the months of July – December, with the greatest cooling in the month of November. The maximum underwent both substantial increases and decreases over different months, causing the opposing trends to cancel out to some extent. Minimum temperatures, on the other hand, underwent greater increases than decreases over the 12 months of the year. Even those stations that had mean annual cooling trends over the 1938–1995 period had the greatest warming in March. Cooling occurred in the months of July – December, with the greatest cooling taking place in November. Gan (1998), who also found warming during the months of January, March, April, and June on the Canadian prairies, concluded that the monthly temperature trends are likely an indication of a broad-scale response to a systematic forcing mechanism, likely the enhanced greenhouse effect.

6.5 GCM Simulations

Of all three of the time periods examined with the GCM outputs, the greatest warming was predicted over the longest period, 1900–2100, most likely because CO_2 concentrations are predicted to double and then triple between 2000 and 2100 (CCCma, 1999).

Temperature trends estimated by the GCM outputs were very different from the trends observed in Alberta. The GCM trends were much weaker than the trends actually observed. However, modellers have repeatedly warned that global climate model results represent climate variation on a large scale and do not have the resolution required to accurately portray a regional system. In spite of this, the GCM outputs did provide an approximation of temperature change in Alberta under conditions of increasing concentrations of greenhouse gases and aerosols. The GHG results were closer to the observed temperature trends than the GHG+A results.

An explanation for the GCM trends being smaller than the observed trends is that simple averaging was used to calculate the observed warming trends for Alberta. Trends in the observational data would most likely be smaller with optimal averaging (Shen, 1999).

7.0 CONCLUSIONS

Temperature variation was investigated for the province of Alberta. Historical temperature data, as well as temperature predictions from GCM outputs, were analyzed to identify trends in mean, minimum, and maximum temperatures. Temperature trends were examined over different time periods and the degrees of warming over different periods were compared. A spatial comparison was performed, contrasting the observed trends at different stations across Alberta. In addition to annual trends, monthly trends in the observational temperature data were examined. The simulated (GCM) data were used not only to predict future temperature trends, but also to compare with trends actually observed in Alberta.

7.1 Observed Trends

Observed trends in mean, minimum, and maximum temperatures were investigated for 25 climate stations across Alberta and the trends were calculated over two time frames, 1938–1995 and 1960–1995. Warming occurred over both time periods in Alberta. The mean warming, given by the average of all 25 stations, was approximately 0.6°C, or 0.1°C/decade, over the 1938–1995 period, and 1.3°C, or 0.4°C/decade, over the 1960–1995 period. This indicates that the average rate of warming in Alberta over the shorter, more recent time frame was approximately four times the average rate of warming over the entire time period.

Over the 1938–1995 period, the greatest warming trend was found in Banff, where the mean temperature increased 0.22°C/decade, for a total warming of 1.3°C over the 58-year period. As a result, the greatest area of warming was found in the south-central part of Alberta. Cooling during the 1938–1995 period was found in the southwestern corner, surrounding Carway. Over the 1960–1995 period, the greatest warming trend was found in Beaverlodge, where the mean temperature increased 0.56°C/decade, giving an overall warming of 2.0°C over the 36-year period. Consequently, the area of greatest warming was in the north-central part of Alberta. No cooling trends were observed in Alberta over the 1960–1995 period.

Minimum temperatures in Alberta increased more than maximums over the 1938–1995 period. The greatest warming trend over the 58 years was found in the minimum temperature, 0.34°C/decade at Banff; but the greatest cooling trend over the same period was also found in the minimum, 0.07°C/decade at Pincher Creek. Conversely, over the shorter time period of 1960–1995, the increases in minimums and maximums were comparable, with the maximum temperature increasing at a rate of only 0.02°C/decade more than the minimum. The greatest warming in Alberta over the shorter 1960–1995 period was found in the maximum, 0.62°C/decade at Beaverlodge. No decreasing trends were observed in the minimum or maximum over the 1960–1995 period.

Over 1938–1995, only 5 of the 25 stations had minimum temperature trends that were statistically significant at the 10% level and no maximum temperature trends over this 58-year period were found to be significant. However, over 1960–1995, there were 15 stations with significant maximum trends and 19 stations with significant minimum trends (at the 10% level).

Monthly temperature trends were similar at all Alberta stations; even for widely separated stations. This indicates that there is high correlation among the Alberta sites. The warming occurred over the

months of January – June with the greatest warming occurring in March. The southeastern corner of Alberta experienced the greatest warming in March.

Among the 25 climate stations in Alberta, the magnitude of monthly warming was generally greater for the maximum temperature than for the minimum, especially in the southern part of the province. However, because substantial decreases in maximum temperature also occurred in some months, the overall warming was greater for the minimum temperature. Therefore, maximum temperature change in Alberta occurred with greater variability than minimum temperature change. Whether stations had mean annual cooling or warming over the 1938–1995 period, the greatest monthly warming was generally found in the month of March and the greatest monthly cooling generally took place in November or December.

7.2 Observed vs Estimated Trends

Over the 1900–2100 period, the GCM predicted a 7.0°C increase in the mean temperature in Alberta in the GHG run and a 5.3°C increase in the GHG+A run. The amount of warming predicted by the GHG+A run was consistently less than that predicted by the GHG run. When temperature trends were compared over the two centuries (1900–1999 and 2000–2100), the warming simulated over the latter century was approximately five times the magnitude of warming simulated over the former. Over the two centuries, minimum temperature was forecast to increase more than maximum temperature in Alberta. In general, the model suggests that the most substantial warming in Alberta will occur after the year 2000.

The mean temperature increase estimated by the GHG run over the 1960–1995 period was 0.7°C, making it approximately four times the warming estimated for the 1938–1995 period, 0.2°C. The GHG+A run, on the other hand, estimated a mean temperature increase of 0.2°C over the 1960–1995 period, and a mean temperature decrease of 0.6°C over the entire 1938–1995 period.

In terms of simulating temperature trends for the province of Alberta, the GCM results were greatly different from observations at the scale of Alberta. Both GCM runs gave temperature trends that were much smaller than the warming trends actually observed in Alberta over the 1938–1995 and 1960–1995 periods. The GHG results were different from the actual warming by approximately 0.5°C and the GHG+A results were different from the actual warming by approximately 1°C.

When observed temperature trends at individual stations were compared to the GCM trends for Alberta, most stations had trends that were greater than those estimated by the GCM. Close matches between the trends observed at individual stations and the estimated trends were found at only three stations for the maximum temperature over the 1938–1995 period, and at only one station for the minimum temperature over the 1960–1995 period. There were no close matches between individual station trends and trends estimated by the GHG+A run. These results show that it is not appropriate to apply GCM output for predicting temperature variation at the scale of Alberta.

8.0 REFERENCES

Bloomfield, P. and D. Nychka, 1992. Climate spectra and detecting climate change. Climate Change **21**: 275-287.

CCCma – Canadian Centre for Climate Modelling and Analysis, 1999. CCCma Homepage. URL: http://www.cccma.bc.ec.gc.ca/eng_index.html, accessed Sept 1999. Copyright Canadian Centre for Climate Modelling and Analysis, 1999.

Chatfield, C., 1988. Problem Solving: A statistician's guide. Chapman and Hall, New York, NY. xiii + 261pp.

City of Grande Prairie, 2000. City of Grande Prairie Municipal Website; City Profile: Population demographics. URL: http://www.city.grande-prairie.ab.ca/ec_dmgr.htm, accessed May 2000. City of Grande Prairie, Alberta, Canada.

DeMers, M.N., 1997. Fundamentals of Geographic Information Systems. John Wiley & Sons, Inc., New York, NY. xvii + 486pp.

EC – Environment Canada, 1997. A Primer on Climate Change: Understanding climate change. URL: http://www.ec.gc.ca/climate/primer/sec-4.htm, accessed Nov 1999. Copyright Environment Canada, 1997. All rights reserved.

EC – Environment Canada, 1998. Global Climate Change: What is climate change? URL: http://www.ec.gc.ca/climate/whatis/index.html, accessed Nov 1999. Copyright Environment Canada, 1998. All rights reserved.

EC – Environment Canada, 1999a. 1998 – The warmest year on record. URL: http://www.ec.gc.ca/press/1998_m_e.htm, accessed Nov 1999. Copyright Environment Canada, 1999. All rights reserved.

EC – Environment Canada, 1999b. Environmental Priority: Climate change. URL: http://www.ec.gc.ca/envpriorities/climatechange_e.htm, accessed Nov 1999. Copyright Environment Canada, 1999. All rights reserved.

EC – Environment Canada, 1999c. Global Climate Change: Impacts of climate change. URL: http://climatechange.gc.ca/english/html/impacts.html, accessed Nov 1999. Copyright Environment Canada, 1999. All rights reserved.

Finlayson-Pitts, B.J. and J.N. Pitts, 2000. Chemistry of the Upper and Lower Atmosphere: Theory, experiments, and applications. Academic Press, San Diego, California. xxii + 969pp.

Gan, T.Y., 1998. Hydroclimatic trends and possible climatic warming in the Canadian Prairies. Water Resources Research **34**: 3009-3015.

IPCC – Intergovernmental Panel on Climate Change, 1996. Climate Change 1995: The science of climate change. J.T. Houghton, F.G. Meira Filho, B.A. Callendar, N. Harris, A. Kattenberg and K. Maskell (eds.), Cambridge University Press, New York. 570pp.

Johnston, J., 1984. Econometric methods, 3rd ed. McGraw Hill, New York. viii + 568pp.

Karl, T.R., P.D. Jones, R.W. Knight, G. Kukla, N. Plummer, V. Razuvayev, K.P. Gallo, J. Lindseay, R.J. Charlson and T.C. Peterson, 1993. A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. Bulletin of the American Meteorological Society **74**: 1007-1023.

Khandekar, M.L., 2000. Uncertainties in greenhouse gas induced climate change. Report prepared for Science and Technology Branch, Alberta Environment, ISBN 0-7785-1051-4, Edmonton Alberta.

Keckler, D., 1997. Surfer® for Windows User Guide: Contouring and 3D surface mapping, 6th ed. Golden Software, Inc., CO, USA. Copyright Golden Software, Inc., 1997.

Moran, J.M. and M.D Morgan, 1997. Meteorology: The atmosphere and the science of weather, 5th ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey. xiii + 530pp., illustrated.

Pielke, R.A., T. Stohlgren, W. Parton, N. Doesken, J. Money, L. Schell, and K. Redmond, 2000. Spatial representativeness of temperature measurements from a single site. Bulletin of the American Meteorological Society **81**: 826-830.

Shen, S.S., 1999. An assessment of the change in temperature and precipitation in Alberta. Report prepared for Science and Technology Branch, Alberta Environment, No. 98-0282, Edmonton, Alberta.

Trefil, J., 1999. How hot will it get? Time: The weekly newsmagazine **154**, no. 19, November 8, 1999: 78-79.

Vincent, L.A., 1997. A technique for the identification of inhomogeneities in Canadian temperature series. Journal of Climate **11**: 1094 – 1104.

Vincent, L.A. and D.W. Gullet, 1999. Canadian historical and homogeneous temperature datasets for climate change analyses. International Journal of Climatology **19**: 1375-1388.

Wheaton, E., 1998. But It's a Dry Cold! – Weathering the Canadian prairies. Fifth House Ltd. Calgary, Alberta. 184pp., illustrated.

Wigley, T.M.L., 1999. The Science of Climate Change: Global and U.S. perspectives. Report prepared for the Pew Center on Global Climate Change, Arlington, VA. URL: http://www.pewclimate.org/projects/env_science.html, accessed April 2000.

Wong, R.K.W., M. English, F.D. Barlow, L. Cheng and K.R. Tremaine, 1989. Towards a strategy for adapting to climate change in Alberta. Report for Alberta Agriculture, Alberta Environment, Alberta Forestry, Lands and Wildlife, Alberta Technology, Research and Telecommunications and Alberta Research Council. Alberta Research Council, Resource Technologies Department, Edmonton Alberta.

Woodward, W.A. and H.L. Gray, 1993. Global warming and the problem of testing for trend in time series data. Journal of Climate **6**: 953-962.

Zhang, X., L.A. Vincent, W.D. Hogg and A. Niitsoo, 2000. Temperature and precipitation trends in Canada during the 20th century. Atmosphere-Ocean **38**: 395-429

APPENDICES

Appendix I Statistical Tests for the Significance of Trends

The temperature trends in the present study were estimated using the classical least-squares regression of the variable against time. The model included a simple linear trend represented by a straight line. This is a useful first approximation of the time variation of temperature data, although other models may also be used. The trends were classified as significant when the t-test for the regression coefficient concluded that it was significantly different from zero. The significance level used was $\alpha = 0.05$. However, since persistence (autocorrelation) often exists in temperature and other meteorological data, it is necessary to take it into consideration when testing for temperature trends.

Autocorrelation is most often seen in time series analysis, when a set of observations are made sequentially through time (Chatfield, 1988). Autocorrelation describes a data set that is not randomly distributed, but rather, each observation depends upon the preceding observations. That is to say, present values are determined by values in the past. The minimum and the maximum temperature data were tested for autocorrelation at each individual station. Of the 25 stations, 11 showed significant persistence in the minimum temperature trend and 10 showed significant persistence in the maximum trend. The annual minimum and maximum temperature trends were then tested for significance as described below.

Each climate station has different data characteristics; the approach is to consider each station separately when testing for trend significance. For each station, the residuals from the regression were tested for persistence using the Durbin-Watson statistic (see Johnston, 1984 for example). If there was no significant persistence, the classical t-test was used to test for the trend. When significant persistence existed, the test proposed by Bloomfield and Nychka (1992) and applied in Woodward and Gray (1993) was used to test for trend significance.

The Bloomfield and Nychka test is based on an estimate of the variance in the regression coefficient, which takes into account the autocorrelation of the regression residuals. Specifically, an autoregressive (AR) process was fitted to the residuals and the power spectrum of the AR process was used in calculating the variance of the regression coefficient. The final prediction error (FPE) was used in determining the best-fit order of the AR process. A white-noise test followed to ensure that the autocorrelation was adequately represented.

For the Alberta temperature data, the best-fit AR model identified was essentially first-order. This means that the temperature of a given year depends significantly only on that of the previous year.

Kriging – Gridding Method

Kriging was the gridding method used for plotting the contour maps included in this report. Kriging is a geostatistical method that, by using weighted average interpolation algorithms, produces contour plots and attempts to express trends that are suggested in the data (Keckler, 1997). Kriging is an exact interpolation method, which frequently gives a relatively accurate measure of the magnitude of missing values (DeMers, 1997). It interpolates the missing grid values based on the apparent nature of how the given data change with distance.

Appendix II **Results of Statistical Tests**

Table AII.1 Significance in minimum and maximum temperature trends, 1938–1995 (°C/decade)

STATION	Min Temp Trend	Significant? 5%	Significant? 10%	Max Temp Trend	Significant? 5%	Significant? 10%
Banff	0.34	✓	✓	0.10	✗	✗
Beaverlodge CDA	0.21	✗	✗	-0.01	✗	✗
Calgary Int A	0.11	✗	✗	0.01	✗	✗
Calmar	0.19	✗	✗	0.11	✗	✗
Calmar / Edmonton Int A	0.19	✗	✗	0.02	✗	✗
Campsie	0.19	✗	✗	0.04	✗	✗
Carway	-0.03	✗	✗	0.01	✗	✗
Coronation / Coronation A	0.26	✓	✓	0.09	✗	✗
Edson / Edson / Edson A	0.19	✗	✗	-0.002	✗	✗
Entrance	0.07	✗	✗	0.08	✗	✗
Fairview / Peace River A	0.16	✗	✗	-0.006	✗	✗
Fort Chipewyan / Embarras A / Fort Chipewyan A	0.13	✗	✗	-0.01	✗	✗
Fort McMurray / Fort McMurray A	0.11	✗	✗	0.07	✗	✗
Fort Vermilion CDA / High Level A	0.18	✗	✓	0.02	✗	✗
Gleichen	0.09	✗	✗	0.12	✗	✗
Grande Prairie / Grande Prairie A	0.14	✗	✗	0.09	✗	✗
Iron River / Cold Lake A	0.25	✗	✓	0.01	✗	✗
Lacombe CDA	0.13	✗	✓	0.04	✗	✗
Lethbridge A	-0.04	✗	✗	0.13	✗	✗
Lethbridge / Lethbridge CDA	0.06	✗	✗	0.08	✗	✗
Manyberries CDA	0.11	✗	✗	0.12	✗	✗
Medicine Hat A	0.12	✗	✗	0.14	✗	✗
Pincher Creek Town / Pincher Creek / Pincher Creek A	-0.07	✗	✗	0.11	✗	✗
Rocky M H / Rocky M H / Rocky Mt House (Aut)	0.15	✗	✗	0.08	✗	✗
Slave Lake / Slave Lake A	0.16	✗	✗	0.02	✗	✗

Table AII.2 Significance in minimum and maximum temperature trends, 1960–1995 (°C/decade)

STATION	Min Temp Trend	Significant? 5%	Significant? 10%	Max Temp Trend	Significant? 5%	Significant? 10%
Banff	0.26	✓	✓	0.17	✗	✗
Beaverlodge CDA	0.50	✓	✓	0.62	✓	✓
Calgary Int A	0.42	✓	✓	0.30	✗	✓
Calmar	0.40	✓	✓	0.48	✗	✓
Calmar / Edmonton Int A	0.40	✓	✓	0.43	✗	✗
Campsie	0.46	✓	✓	0.50	✗	✓
Carway	0.20	✗	✗	0.23	✗	✗
Coronation / Coronation A	0.36	✓	✓	0.26	✗	✗
Edson / Edson / Edson A	0.31	✓	✓	0.23	✗	✗
Entrance	0.28	✗	✓	0.39	✓	✓
Fairview / Peace River A	0.50	✗	✓	0.45	✗	✗
Fort Chipewyan / Embarras A / Fort Chipewyan A	0.47	✓	✓	0.42	✓	✓
Fort McMurray / Fort McMurray A	0.46	✓	✓	0.47	✓	✓
Fort Vermilion CDA / High Level A	0.19	✗	✗	0.31	✓	✓
Gleichen	0.29	✗	✓	0.44	✓	✓
Grande Prairie / Grande Prairie A	0.42	✓	✓	0.51	✗	✓
Iron River / Cold Lake A	0.32	✓	✓	0.37	✓	✓
Lacombe CDA	0.29	✓	✓	0.40	✓	✓
Lethbridge A	0.11	✗	✗	0.24	✗	✗
Lethbridge / Lethbridge CDA	0.33	✓	✓	0.21	✗	✗
Manyberries CDA	0.26	✗	✗	0.48	✓	✓
Medicine Hat A	0.24	✗	✗	0.28	✗	✗
Pincher Creek Town / Pincher Creek / Pincher Creek A	0.18	✗	✗	0.25	✗	✗
Rocky M H / Rocky M H / Rocky Mt House (Aut)	0.44	✓	✓	0.27	✓	✓
Slave Lake / Slave Lake A	0.58	✓	✓	0.45	✗	✓

Table AIII.1 Monthly temperature trends, 1938–1995

Banff

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.44	2.5	0.57	3.3	0.30	1.8
Feb	0.54	3.1	0.70	4.1	0.37	2.2
Mar	0.65	3.8	0.76	4.4	0.54	3.2
Apr	0.29	1.7	0.40	2.3	0.18	1.0
May	0.21	1.2	0.36	2.1	0.05	0.3
Jun	0.36	2.1	0.40	2.3	0.32	1.9
Jul	0.05	0.3	0.28	1.6	-0.19	-1.1
Aug	0.25	1.5	0.45	2.6	0.06	0.3
Sep	0.09	0.5	0.18	1.0	0	0
Oct	0.05	0.3	0.06	0.3	0.05	0.3
Nov	-0.09	-0.5	0.02	0.1	-0.19	-1.1
Dec	-0.24	-1.4	-0.16	-0.9	-0.32	-1.8

Beaverlodge CDA

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.34	2.0	0.39	2.3	0.29	1.7
Feb	0.32	1.9	0.40	2.3	0.25	1.4
Mar	0.40	2.3	0.48	2.8	0.32	1.8
Apr	0.29	1.7	0.32	1.9	0.26	1.5
May	0.09	0.5	0.17	1.0	0.01	0.1
Jun	0.11	0.6	0.27	1.6	-0.05	-0.3
Jul	-0.07	-0.4	0.16	0.9	-0.31	-1.8
Aug	0.06	0.3	0.27	1.6	-0.15	-0.9
Sep	-0.09	-0.5	0.11	0.7	-0.30	-1.7
Oct	-0.10	-0.6	0.03	0.2	-0.22	-1.3
Nov	-0.17	-1.0	-0.14	-0.8	-0.20	-1.2
Dec	0	0	-0.02	-0.1	0.03	0.2

Calgary Int A

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.34	2.0	0.30	1.7	0.38	2.2
Feb	0.61	3.6	0.66	3.9	0.56	3.3
Mar	0.61	3.5	0.57	3.3	0.64	3.7
Apr	0.18	1.0	0.17	1.0	0.19	1.1
May	0.02	0.1	0.08	0.4	-0.03	-0.2
Jun	0.22	1.3	0.22	1.3	0.21	1.2
Jul	-0.24	-1.4	-0.02	-0.1	-0.47	-2.7
Aug	-0.02	-0.1	0.17	1.0	-0.22	-1.3
Sep	-0.16	-0.9	-0.10	-0.6	-0.23	-1.3
Oct	-0.23	-1.3	-0.16	-0.9	-0.30	-1.8
Nov	-0.28	-1.6	-0.24	-1.4	-0.33	-1.9
Dec	-0.27	-1.6	-0.31	-1.8	-0.23	-1.3

Calmar

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.49	2.9	0.59	3.4	0.39	2.3
Feb	0.58	3.3	0.62	3.6	0.53	3.1
Mar	0.62	3.6	0.67	3.9	0.57	3.3
Apr	0.32	1.9	0.23	1.4	0.42	2.4
May	0.19	1.1	0.17	1.0	0.21	1.2
Jun	0.25	1.4	0.27	1.6	0.22	1.3
Jul	-0.19	-1.1	-0.08	-0.5	-0.30	-1.7
Aug	0.03	0.2	0.10	0.6	-0.05	-0.3
Sep	-0.01	-0.05	0.08	0.5	-0.09	-0.5
Oct	-0.01	-0.1	0.10	0.6	-0.12	-0.7
Nov	-0.29	-1.7	-0.33	-1.9	-0.25	-1.4
Dec	-0.24	-1.4	-0.29	-1.7	-0.20	-1.2

Calmar/Edmonton Int A

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.51	3.0	0.59	3.4	0.43	2.5
Feb	0.60	3.5	0.64	3.7	0.57	3.3
Mar	0.66	3.8	0.75	4.4	0.57	3.3
Apr	0.18	1.0	0.22	1.3	0.13	0.8
May	0.02	0.1	0.08	0.4	-0.04	-0.2
Jun	0.12	0.7	0.20	1.2	0.04	0.3
Jul	-0.16	-0.9	0.02	0.1	-0.33	-1.9
Aug	0	0	0.15	0.8	-0.14	-0.8
Sep	-0.11	-0.6	0.05	0.3	-0.27	-1.5
Oct	-0.18	-1.0	-0.07	-0.4	-0.28	-1.6
Nov	-0.22	-1.3	-0.18	-1.1	-0.26	-1.5
Dec	-0.10	-0.6	-0.14	-0.8	-0.06	-0.3

Campsie

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.35	2.0	0.39	2.3	0.30	1.8
Feb	0.45	2.6	0.44	2.5	0.47	2.7
Mar	0.55	3.2	0.67	3.9	0.43	2.5
Apr	0.22	1.3	0.22	1.3	0.21	1.2
May	0.05	0.3	0.06	0.4	0.04	0.2
Jun	0.19	1.1	0.27	1.6	0.11	0.6
Jul	-0.08	-0.5	0.09	0.5	-0.25	-1.5
Aug	0.08	0.5	0.27	1.5	-0.11	-0.6
Sep	-0.08	-0.5	0.09	0.5	-0.26	-1.5
Oct	-0.17	-1.0	-0.04	-0.3	-0.29	-1.7
Nov	-0.16	-1.0	-0.14	-0.8	-0.19	-1.1
Dec	-0.02	-0.1	-0.08	-0.5	0.05	0.3

Table AIII.1 (continued)

Carway	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.26	1.5	0.16	0.9	0.36	2.1
Feb	0.51	2.9	0.39	2.3	0.62	3.6
Mar	0.67	3.9	0.63	3.6	0.70	4.1
Apr	0.07	0.4	0.07	0.4	0.06	0.4
May	-0.02	-0.1	-0.02	-0.1	-0.01	-0.1
Jun	0.18	1.0	0.05	0.3	0.30	1.7
Jul	-0.37	-2.2	-0.27	-1.6	-0.47	-2.8
Aug	-0.25	-1.4	-0.12	-0.7	-0.37	-2.1
Sep	-0.18	-1.0	-0.23	-1.3	-0.13	-0.8
Oct	-0.26	-1.5	-0.23	-1.3	-0.29	-1.7
Nov	-0.34	-2.0	-0.32	-1.9	-0.36	-2.1
Dec	-0.39	-2.3	-0.47	-2.7	-0.31	-1.8

Coronation/Coronation A	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.34	2.0	0.55	3.2	0.13	0.7
Feb	0.68	3.9	0.76	4.4	0.60	3.5
Mar	0.82	4.8	0.86	5.0	0.79	4.6
Apr	0.34	2.0	0.28	1.6	0.39	2.3
May	0.16	0.9	0.18	1.0	0.14	0.8
Jun	0.34	2.0	0.27	1.6	0.40	2.3
Jul	-0.16	-0.9	0	0	-0.33	-1.9
Aug	0.05	0.3	0.18	1.0	-0.08	-0.5
Sep	-0.03	-0.2	0.06	0.4	-0.13	-0.7
Oct	-0.08	-0.4	0	0	-0.16	-0.9
Nov	-0.09	-0.5	0.07	0.4	-0.24	-1.4
Dec	-0.25	-1.4	-0.04	-0.2	-0.46	-2.7

Edson/Edson A	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.20	1.2	-0.06	-0.4	0.46	2.7
Feb	0.29	1.7	0.29	1.7	0.29	1.7
Mar	0.41	2.4	0.46	2.7	0.36	2.1
Apr	0.28	1.6	0.41	2.4	0.14	0.8
May	0.12	0.7	0.30	1.8	-0.06	-0.4
Jun	0.21	1.2	0.42	2.4	-0.01	0.0
Jul	-0.04	-0.3	0.30	1.7	-0.39	-2.3
Aug	0.10	0.6	0.43	2.5	-0.22	-1.3
Sep	-0.09	-0.5	0.17	1.0	-0.35	-2.0
Oct	-0.03	-0.2	0.13	0.8	-0.19	-1.1
Nov	-0.20	-1.1	-0.29	-1.7	-0.11	-0.6
Dec	-0.13	-0.8	-0.34	-2.0	0.08	0.4

Entrance	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.45	2.6	0.39	2.2	0.50	2.9
Feb	0.37	2.2	0.35	2.0	0.40	2.3
Mar	0.41	2.4	0.40	2.3	0.42	2.4
Apr	0.25	1.4	0.18	1.0	0.31	1.8
May	0.05	0.3	0.05	0.3	0.06	0.3
Jun	0.15	0.9	0.13	0.8	0.16	0.9
Jul	-0.10	-0.6	0.02	0.1	-0.22	-1.3
Aug	0.02	0.1	0.08	0.5	-0.04	-0.3
Sep	-0.13	-0.8	-0.08	-0.5	-0.17	-1.0
Oct	-0.13	-0.7	-0.14	-0.8	-0.11	-0.7
Nov	-0.22	-1.2	-0.31	-1.8	-0.12	-0.7
Dec	-0.22	-1.3	-0.29	-1.7	-0.14	-0.8

Fairview/Peace River A	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.19	1.1	0.29	1.7	0.09	0.5
Feb	0.31	1.8	0.37	2.1	0.26	1.5
Mar	0.53	3.1	0.65	3.8	0.42	2.4
Apr	0.39	2.3	0.39	2.3	0.39	2.3
May	0.13	0.8	0.18	1.1	0.08	0.5
Jun	0.19	1.1	0.33	1.9	0.06	0.3
Jul	-0.10	-0.6	0.05	0.3	-0.25	-1.4
Aug	0.03	0.2	0.18	1.0	-0.13	-0.7
Sep	-0.15	-0.9	0	0	-0.29	-1.7
Oct	-0.12	-0.7	-0.01	-0.1	-0.24	-1.4
Nov	-0.36	-2.1	-0.40	-2.3	-0.32	-1.9
Dec	-0.19	-1.1	-0.22	-1.3	-0.16	-1.0

Fort Chipewyan/Embarras A/Fort Chipewyan A	Mean °C/dec	Mean °C/58 y	Min °C/dec	Min °C/58 y	Max °C/dec	Max °C/58 y
Jan	0.31	1.8	0.25	1.4	0.37	2.2
Feb	0.65	3.8	0.64	3.7	0.66	3.8
Mar	0.42	2.5	0.42	2.4	0.43	2.5
Apr	0.42	2.4	0.56	3.2	0.29	1.7
May	0.16	0.9	0.23	1.4	0.09	0.5
Jun	0.22	1.3	0.46	2.6	0	0
Jul	-0.04	-0.2	0.20	1.2	-0.28	-1.6
Aug	0.01	0.1	0.20	1.2	-0.18	-1.1
Sep	-0.24	-1.4	-0.15	-0.9	-0.33	-1.9
Oct	-0.34	-2.0	-0.20	-1.2	-0.48	-2.8
Nov	-0.52	-3.0	-0.59	-3.4	-0.45	-2.6
Dec	-0.40	-2.3	-0.53	-3.1	-0.28	-1.6

Table AIII.1 (continued)

Fort McMurray/ Fort McMurray A

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.37	2.2	0.26	1.5	0.48	2.8
Feb	0.56	3.3	0.47	2.7	0.66	3.8
Mar	0.42	2.5	0.34	2.0	0.51	2.9
Apr	0.36	2.1	0.48	2.8	0.25	1.4
May	0.14	0.8	0.13	0.8	0.15	0.9
Jun	0.24	1.4	0.44	2.5	0.03	0.2
Jul	-0.14	-0.8	0.08	0.4	-0.36	-2.1
Aug	-0.03	-0.2	0.09	0.5	-0.16	-0.9
Sep	-0.09	-0.5	0.02	0.1	-0.20	-1.1
Oct	-0.24	-1.4	-0.08	-0.5	-0.40	-2.3
Nov	-0.40	-2.3	-0.54	-3.1	-0.27	-1.6
Dec	-0.16	-0.9	-0.42	-2.4	0.10	0.6

Fort Vermilion CDA/High Level A

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.39	2.3	0.32	1.8	0.46	2.7
Feb	0.56	3.2	0.56	3.2	0.55	3.2
Mar	0.41	2.4	0.45	2.6	0.36	2.1
Apr	0.44	2.5	0.50	2.9	0.37	2.2
May	0.11	0.6	0.16	0.9	0.07	0.4
Jun	0.13	0.8	0.32	1.8	-0.05	-0.3
Jul	-0.10	-0.6	0.15	0.9	-0.34	-2.0
Aug	-0.02	-0.1	0.20	1.2	-0.25	-1.4
Sep	-0.15	-0.9	-0.03	-0.2	-0.27	-1.6
Oct	-0.21	-1.2	-0.02	-0.1	-0.39	-2.3
Nov	-0.45	-2.6	-0.47	-2.8	-0.43	-2.5
Dec	-0.04	-0.2	-0.27	-1.6	0.20	1.1

Gleichen

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.36	2.1	0.37	2.1	0.35	2.0
Feb	0.71	4.1	0.78	4.5	0.64	3.7
Mar	0.71	4.1	0.59	3.4	0.83	4.8
Apr	0.12	0.7	0.02	0.09	0.23	1.3
May	-0.04	-0.2	-0.09	-0.5	0	0
Jun	0.23	1.3	0.06	0.4	0.39	2.3
Jul	-0.23	-1.3	-0.17	-1.0	-0.28	-1.6
Aug	0.04	0.2	0.07	0.4	0	0
Sep	-0.14	-0.8	-0.18	-1.0	-0.10	-0.6
Oct	-0.16	-0.9	-0.11	-0.7	-0.21	-1.2
Nov	-0.15	-0.9	-0.12	-0.7	-0.19	-1.1
Dec	-0.13	-0.8	-0.10	-0.6	-0.16	-0.9

Grande Prairie/Grande Prairie A

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.31	1.8	0.33	1.9	0.30	1.7
Feb	0.46	2.6	0.43	2.5	0.48	2.8
Mar	0.57	3.3	0.68	3.9	0.47	2.7
Apr	0.36	2.1	0.32	1.8	0.40	2.3
May	0.08	0.5	0.10	0.6	0.06	0.4
Jun	0.15	0.9	0.22	1.3	0.09	0.5
Jul	-0.10	-0.6	0	0	-0.19	-1.1
Aug	0.02	0.1	0.11	0.6	-0.07	-0.4
Sep	-0.11	-0.6	0	0	-0.22	-1.3
Oct	-0.07	-0.4	-0.04	-0.2	-0.09	-0.5
Nov	-0.25	-1.4	-0.33	-1.9	-0.17	-1.0
Dec	-0.05	-0.3	-0.13	-0.8	0.03	0.2

Iron River/Cold Lake A

	Mean		Min		Max	
	°C/dec	°C/58yrs	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.35	2.1	0.53	3.1	0.18	1.0
Feb	0.57	3.3	0.74	4.3	0.41	2.4
Mar	0.73	4.2	0.85	5.0	0.60	3.5
Apr	0.33	1.9	0.39	2.2	0.28	1.6
May	0.14	0.8	0.21	1.2	0.07	0.4
Jun	0.32	1.9	0.44	2.5	0.20	1.2
Jul	-0.06	-0.3	0.13	0.8	-0.25	-1.5
Aug	0.06	0.4	0.19	1.1	-0.06	-0.4
Sep	-0.05	-0.3	0.14	0.8	-0.24	-1.4
Oct	-0.17	-1.0	-0.02	-0.1	-0.33	-1.9
Nov	-0.17	-1.0	-0.10	-0.6	-0.24	-1.4
Dec	-0.25	-1.5	-0.05	-0.3	-0.46	-2.7

Lacombe CDA

	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.40	2.3	0.47	2.7	0.32	1.9
Feb	0.56	3.3	0.60	3.5	5.22	3.0
Mar	0.63	3.7	0.69	4.0	0.57	3.3
Apr	0.25	1.5	0.20	1.1	0.31	1.8
May	0.08	0.4	0.05	0.3	0.10	0.6
Jun	0.20	1.1	0.24	1.4	0.16	0.9
Jul	-0.27	-1.5	-0.09	-0.5	-0.44	-2.5
Aug	-0.02	-0.09	0.13	0.8	-0.16	-0.9
Sep	-0.11	-0.6	-0.07	-0.4	-0.15	-0.9
Oct	-0.14	-0.8	-0.05	-0.3	-0.23	-1.3
Nov	-0.34	-2.0	-0.28	-1.6	-0.41	-2.4
Dec	-0.28	-1.6	-0.27	-1.6	-0.29	-1.7

Table AIII.1 (continued)

Lethbridge A	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.25	1.4	0.17	1.0	0.32	1.9
Feb	0.57	3.3	0.44	2.6	0.69	4.0
Mar	0.64	3.7	0.44	2.6	0.84	4.9
Apr	0.13	0.8	0.02	0.1	0.25	1.5
May	0.07	0.4	-0.01	-0.07	0.16	0.9
Jun	0.27	1.6	0.13	0.8	0.41	2.4
Jul	-0.32	-1.9	-0.21	-1.2	-0.44	-2.5
Aug	-0.08	-0.5	-0.02	-0.1	-0.14	-0.8
Sep	-0.15	-0.9	-0.29	-1.7	0	0
Oct	-0.23	-1.3	-0.34	-2.0	-0.13	-0.7
Nov	-0.22	-1.3	-0.30	-1.7	-0.15	-0.9
Dec	-0.43	-2.5	-0.58	-3.4	-0.28	-1.6

Lethbridge/Lethbridge CDA	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.27	1.6	0.32	1.8	0.22	1.3
Feb	0.57	3.3	0.60	3.5	0.54	3.1
Mar	0.61	3.6	0.60	3.5	0.63	3.7
Apr	0.13	0.8	0.08	0.5	0.18	1.1
May	0.10	0.6	0.03	0.2	0.17	1.0
Jun	0.27	1.6	0.11	0.6	0.43	2.5
Jul	-0.27	-1.6	-0.18	-1.1	-0.36	-2.1
Aug	-0.01	-0.1	0.02	0.1	-0.04	-0.3
Sep	-0.11	-0.6	-0.19	-1.1	-0.02	-0.1
Oct	-0.23	-1.3	-0.25	-1.5	-0.20	-1.2
Nov	-0.21	-1.2	-0.13	-0.8	-0.28	-1.6
Dec	-0.27	-1.6	-0.26	-1.5	-0.28	-1.6

Manyberries CDA	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.45	2.6	0.45	2.6	0.44	2.6
Feb	0.74	4.3	0.67	3.9	0.80	4.7
Mar	0.98	5.7	0.87	5.0	1.10	6.4
Apr	0.11	0.6	0.14	0.8	0.08	0.5
May	0.10	0.6	0.18	1.1	0	0
Jun	0.28	1.6	0.14	0.8	0.41	2.4
Jul	-0.28	-1.6	-0.12	-0.7	-0.45	-2.6
Aug	-0.12	-0.7	-0.02	-0.1	-0.22	-1.3
Sep	-0.24	-1.4	-0.28	-1.6	-0.19	-1.1
Oct	-0.31	-1.8	-0.24	-1.4	-0.37	-2.2
Nov	-0.15	-0.9	-0.19	-1.1	-0.12	-0.7
Dec	-0.17	-1.0	-0.24	-1.4	-0.09	-0.5

Medicine Hat A	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.40	2.3	0.43	2.5	0.37	2.2
Feb	0.80	4.6	0.75	4.4	0.84	4.9
Mar	0.91	5.3	0.74	4.3	1.07	6.2
Apr	0.16	1.0	0.11	0.7	0.22	1.3
May	0.09	0.5	0.09	0.5	0.10	0.6
Jun	0.31	1.8	0.20	1.1	0.43	2.5
Jul	-0.30	-1.7	-0.16	-0.9	-0.43	-2.5
Aug	-0.03	-0.2	0.05	0.3	-0.10	-0.6
Sep	-0.13	-0.8	-0.18	-1.0	-0.09	-0.5
Oct	-0.23	-1.3	-0.21	-1.2	-0.26	-1.5
Nov	-0.18	-1.0	-0.16	-0.9	-0.20	-1.1
Dec	-0.30	-1.7	-0.30	-1.8	-0.29	-1.7

Pincher Crk Town/Pincher Creek/Pincher Crk A	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.31	1.8	0.20	1.2	0.42	2.5
Feb	0.46	2.7	0.38	2.2	0.55	3.2
Mar	0.57	3.3	0.50	2.9	0.64	3.7
Apr	0.12	0.7	0.06	0.3	0.17	1.0
May	0.03	0.2	0	0	0.07	0.4
Jun	0.21	1.2	0.05	0.3	0.38	2.2
Jul	-0.33	-1.9	-0.26	-1.5	-0.39	-2.2
Aug	-0.10	-0.6	-0.06	-0.4	-0.15	-0.8
Sep	-0.12	-0.7	-0.23	-1.3	0	0
Oct	-0.27	-1.6	-0.40	-2.3	-0.14	-0.8
Nov	-0.25	-1.4	-0.26	-1.5	-0.23	-1.3
Dec	-0.32	-1.8	-0.46	-2.7	-0.18	-1.0

Rocky M H/Rocky M H/Rocky Mt House (Aut)	Mean		Min		Max	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.69	4.0	0.58	3.3	0.81	4.7
Feb	0.59	3.4	0.62	3.6	0.57	3.3
Mar	0.46	2.7	0.53	3.1	0.38	2.2
Apr	0.27	1.6	0.22	1.3	0.32	1.8
May	0	0	0.03	0.2	-0.01	-0.08
Jun	0.18	1.0	0.22	1.3	0.14	0.8
Jul	-0.25	-1.4	-0.08	-0.5	-0.41	-2.4
Aug	-0.08	-0.5	0.05	0.3	-0.21	-1.2
Sep	-0.08	-0.5	-0.01	-0.08	-0.14	-0.8
Oct	-0.08	-0.5	0	0	-0.16	-1.0
Nov	-0.26	-1.5	-0.31	-1.8	-0.20	-1.2
Dec	-0.16	-0.9	-0.20	-1.1	-0.11	-0.7

Table AIII.1 (continued)

Slave Lake/Slave Lake A						
	Mean		*Min*		*Max*	
	°C/dec	°C/58 y	°C/dec	°C/58 y	°C/dec	°C/58 y
Jan	0.38	2.2	0.27	1.6	0.49	2.8
Feb	0.47	2.7	0.37	2.2	0.57	3.3
Mar	0.52	3.0	0.57	3.3	0.46	2.7
Apr	0.16	1.0	0.30	1.7	0.03	0.2
May	0.03	0.2	0.21	1.2	-0.14	-0.8
Jun	0.11	0.6	0.31	1.8	-0.09	-0.5
Jul	-0.14	-0.8	0.12	0.7	-0.40	-2.3
Aug	0	0	0.21	1.2	-0.20	-1.2
Sep	-0.16	-0.9	0.03	0.1	-0.34	-2.0
Oct	-0.16	-0.9	-0.10	-0.6	-0.22	-1.3
Nov	-0.23	-1.3	-0.39	-2.3	-0.07	-0.4
Dec	0.02	0.1	-0.17	-1.0	0.20	1.1